PEBBLES

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PEBBLES

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BY

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ILLUSTRATED BY 250 FIGURES

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TO

PROFESSOR JOHN WESLEY JUDD,

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PREFACE

THE portion of the Fund allotted to me with the Murchison Medal by the Council of the Geological Society of London, in 1905, has been applied towards the production of this book on Pebbles.

More than half a century has been spent in acquiring, in different countries, the material necessary for the illustrations, and it is hoped they will prove useful to students of Geology and of Nature generally.

Mr. D. J. Mahony, M.Sc., has seen to the editing, and to him, and to all who have in any way rendered assistance, my warmest thanks are tendered.

E. J. D.

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PEBBLES

CHAPTER I.

MISCELLANEOUS.

Synonyms—What a Pebble is—Size of a Pebble—Some Pebbles the hardest portions of rocks—Pebbles formed from all varieties of rocks—Ages of Pebbles.

Pebbles, singly or in the aggregate, are known by a variety of terms, such as pebbles, beach-stones, shingle, gravel, drift, wash, wash-dirt, cobble-stones, etc. When aggregated and bound together by clay, carbonate of magnesia, carbonate of lime, silica, or iron-oxide, the terms conglomerate and pudding-stone are applied. Local terms in great variety are used to describe pebbles, individually and collectively. Pebbles laid down in flowing water, generally have their longer axes up and down stream. They are often tilted, and rest one upon the other, hence the name, "shingle."

Pebbles are small portions of rock detached from the parent mass that have become more or less rounded. While sharp and angular (Plate 1, Fig. 1), the detached portions may be called fragments, but as soon as these fragments begin to lose their angles, the term pebbles may be applied, for from this stage to the most highly rounded pebble there is every gradation, and no point at which a logical division could be made (Plates 1 to 5, Figs. 1 to 10). Pebbles then are more or less rounded portions of rock that have been shaped by mechanical or chemical agencies, or by a combination of these. From the time that an angular fragment becomes less sharp, whether by atmospheric action, by the insidious disintegration caused by minute organisms, such as lichens and mosses, from chemical causes, or by mechanical wear, it may be considered a pebble, though perhaps only in its initial stage.

It has never been decided up to what size a stone is a pebble and beyond which it should be called a boulder. Nature is closely followed in this respect, for there is every gradation from minute sand grains up to boulders many tons in weight. Still there is a general idea that above a certain size the term pebble is no longer applicable. Anything less than six inches in its longest diameter may be safely called a pebble, and applied to anything larger, the term might be open to objection. The smallest mass included under the term pebble has also been left indeterminate, but the size of a pea might be taken as the lowest limit.

From the manner in which they are produced, it is obvious that some pebbles represent the hardest and most compact portions of the rock from which they have been derived. As a rule only the heart of the stone, or the core, in a well rounded pebble, could have survived the fierce knocks, the long continued abrasion, and the destructive agencies, both physical and chemical, to which it has been subjected, in many cases for vast periods of time. Small well worn pebbles are often all that remain of great boulders or masses of rock, and it has always to be remembered that a pebble is not a finished product, but that it is in a transition stage between the great rock mass from which it was torn and the finest ground silt to which it must finally be reduced.

Pebbles occur of nearly every variety of rock and mineral, and range in hardness from soft clay to the diamond. From platinum, the heaviest of metals, to pumice, the lightest frothy material hurled from volcanoes, and which floats on water, pebbles are formed.

Among the most ancient of the stratified rocks pebbles are found, often distorted, flattened, sheared or impressed, or drawn out to abnormal lengths, but still clearly pebbles, and the process of pebble forming is in active progress now the world over, and the very same processes are at work shaping them by chemical action, by percussion, by abrasion, by wedging minute particles from them, and by slowly etching them away, that shaped them in the dim past. Everywhere the work is ceaselessly proceeding, in the river bed, on the desert surface, on the ocean beach, in the throats of volcanoes, in the crevices of the riven rocks. Stones frozen into the glacier and in the iceberg, or rolled in the maws of animals or birds, are constantly being manufactured into pebbles. So long as the processes of change continue on this globe pebbles will be formed. A pebble broken out from a conglomerate that was originally aggregated in the infancy of the earth may have just recently reached a river bed, as pebbles sometimes rest for long periods; still the time comes when these are again set in motion, and they are once more shaped, the roughness smoothed, the distortion rectified, and they are generally renewed, and in the process are still further reduced in size. A pebble, therefore, fresh from a river bed, and one that looks newly ground, may have been contemporaneous with the earliest rocks exposed at the surface of this earth. Of two pebbles from the bed of a stream having precisely the same appearance, the one may be but a few years or months old while the other of the same material may date from the remote past.

CHAPTER II.

FORMS OF PEBBLES.

Determined by: Composition—Texture—Structure of the original rock—Arrangement of mineral constituents—Resistance to decomposition—Shape of the original rock fragment—Position while being rounded—The agent which fashions them—Classification of forms—The causes producing the various forms.

The forms of pebbles depend on a variety of causes, such as the nature of the material, its texture, the manner in which it is jointed, fissured, or veined; the nature of the veins, whether they are harder or softer than the rest of the body; the disposition of the minerals in the rock, their relative hardness or liability to decompose; the original shape of the piece of rock; the position it occupied while subjected to the percussion of passing pebbles, or the attrition of pebbles and sand; the nature of the bed rock it glided over; the behaviour of its component parts as regards their solubility in water; the manner in which it descended rapids or falls in a stream; whether it was subjected to ice action, to volcanic action, to frost; the position in which it has been exposed to atmospheric action, and generally to an infinitude of conditions. Just as varied as the causes that go to shape pebbles are the forms they assume. Pebbles change in shape in different stages of their career; at one time a sphere, this becomes shattered, and then the fragments are again worn into pebbles of other forms. (Plate 12, Fig. 2.)

Symmetrical pebbles are comparatively rare, but the irregular forms abound, and no two are exactly alike. The regular forms may be roughly classed as, 1st: spheres, or those having all axes equal (Plate 7, Figs. 1, 2, 3); 2nd: ovoid forms and cylinders, or those having one axis longer than the other equal axes (Plate 8, Figs. 1, 2, 3), (Plate 9, Fig. 3); and, 3rd: flattened ovoid forms, or those having three axes at right angles to each other all unequal, such as (Plate 9, Fig. 4). These and sectional portions from them would constitute the more regular forms, while the other shapes are endless in variety and not classifiable. Spherical forms are usually derived from material that is either homogeneous or that consists of grains that offer the same resistance to wear in every direction, such as fine-grained hard siliceous rocks, quartzite, hornfels, lydianite, etc., or granite in its varieties, diorite, compact basalt and rocks of similar texture. All these have a tendency to wear into spherical forms. Perfectly spherical pebbles are nevertheless not common, and the best examples occur either on a rough sea coast or in pot holes.

Spherical quartz pebbles rarely occur, although some about the size of marbles approach the form of spheres. Sections of spheres occur infrequently (Plate 9, Fig. 1). Cylindrical pebbles also are not common. The very lengthening of their particles in schists, etc., which is favourable to their exceeding in length, is generally accompanied by a degree of flattening, and this tends to produce a flattened rather than a regular cylinder. The pebbles that have three more or less unequal axes are far commoner. Thin, nearly circular, discs are plentiful where schists or slates abound and the sea is as rough as it is on the coast at Hokitiki, New Zealand (Plate 9, Fig. 2). Ovate forms of varying thickness are not rare in some localities. Quartz pebbles, when rounded to their limit, generally are of this form, and nearly as thick as wide, but longer than either dimension. Schistose rocks furnish long pebbles, narrow and thin (Plate 10, Figs. 1, 2, 4, 5). Pebbles formed of rock through which quartz veins run are modified by these veins, and as the veins are harder than the rest of the pebbles they project more or less, according to the amount of difference in the hardness of the veins and the mass. The influence of the material in shaping the pebble is shown in an example of kerosene shale (Plate 20, Fig. 3).

The original form of the fragment of rock is determined by the structure of the mass, its joints, laminations, veins and composition, and partly also by the means through which it has become detached; for instance, fragments slowly detached by alternations of cold and heat, moisture and dryness, would differ widely from such as were forcibly and instantaneously removed by a lightning stroke. Among the most common forms of the original fragments that go to form pebbles are irregular angular pieces whose shape is due to the intersection of joints (Plate 11, Fig. 1). Such irregular and unclassifiable forms are by far the most common, but rough cubes, prisms and tabular pebbles also are met with.

The influence of the original form of the fragment becomes in some cases more and more indistinct as the shaping of the pebble proceeds, and is often entirely eliminated after a while. The original fragment may be greatly modified in form by the action of the weather, the growth of lichens and other plants, before it reaches any running water. In some cases there is a tendency for fragments of angular rock as they are detached from the mass to become more or less spherical by decomposition on the outside, so that by the time they reach running water only a little work is required to convert them into well rounded pebbles (Plate 19, Fig. 6). Faults and fissures in the original rock mass are sometimes preserved in pebbles (Plate 17, Figs. 1 and 2).

As to material and texture, it is manifest that they must exercise considerable influence at all stages of the pebble's career. A close-grained hard rock, such as quartzite, would wear away differently to a siliceous schist under the same action. In this case the two rocks are of the same material, but they differ in texture, and the resulting pebbles would differ in form.

Portion of the material composing a pebble may be insoluble in water, while other portions may be soluble, and in this way the form of a pebble is modified. The ultimate shape may also be influenced by the manner in which the shaping is done. A pebble fast in the ice of a glacier might have one or more sides planed down (Plate 55, Figs. 1 and 2). A symmetrical pebble may thus, by means of a glacier, be ground into an irregular-shaped one. A pebble may become firmly set in a crevice among the rocks of a river bed, and by the attrition of the sand, etc., passing over it, the shape may become entirely changed; or when pebbles are exposed to a natural sand blast, their forms may be completely altered (Plate 13, Figs. 1, 2, 3, 4, 5); or angular pieces of rock or sub-angular pebbles may be swirled round in pot holes in streams until they become quite spherical.

The majority of pebbles owe their form more to the material and its texture than to any other cause. This is well exemplified on beaches where many varieties of rock are represented. Schists, slates and similar textured rocks are commonly worn into flattish pebbles of ovoid form (Plate 9, Fig. 4), and in some cases into more or less circular discs (Plate 9, Figs. 1 and 2); granitic crystalline rocks, and such as are homogeneous in texture, wear into more or less spherical forms (Plate 7, Figs. 1, 2, 3); while rocks that have a tendency to split up into long splintery fragments are ground into cylindrical pebbles with rounded ends (Plate 9, Fig. 3).

Alternate layers or bands of different material, as well as differences in the hardness of different portions, influence the form (Plate 12, Figs. 1 and 3). Materials, portions of which decompose more readily than others, modify the shape.

Pebbles formed under special conditions, no matter in what part of the globe, exhibit certain well-marked characteristics. In the case of ice action, the peculiar forms (Plate 56, Figs. 1, 2, 3), the splintered (Plate 56, Figs. 2 and 3), facetted (Plate 55, Figs. 1 and 2), scored (Plate 54, Figs. 1 and 2), striated (Plate 53, Fig. 2), and scratched (Plate 52, Fig. 2) varieties are peculiarly distinctive. Pebbles picked out of a glacier in one part of the world correspond generally with the pebbles furnished by a glacier in any other part of the world, even though separated by great distances. Not only is this the case in existing glaciers, but it holds good with Permian or still older glaciated pebbles, for these cannot be differentiated from those now in process of formation (Plate 56, Figs. 1 and 2).

Pebbles formed in volcanic throats, "dry pebbles," have characteristics that separate them from such as are formed by water action. (Plate 19, Figs. 3 and 4).

A pebble may owe its form to quite a number of distinct influences, and in certain cases these, or some of them, are clearly impressed on it, as in the case of a pebble from the banks of the Orange River at its junction with Diep River, South Africa. It is of ancient amygdaloid (the body of grey colour, the amygdules of red jasper and white quartz), and therefore of igneous origin. It was rounded as a pebble by flowing water, and later a chip was broken off it, probably when it was glaciated. The glaciation partly obliterated the fracture and scored and scratched the pebble, leaving projections where veins and amygdules of jasper and quartz existed. It was then enclosed in the Dwyka conglomerate from which denudation subsequently released it and left it among the pebbles of the Orange River. A Bushman then used it as a hammer, and it was, last of all, the plaything of a Dutch boy.

Pebbles in an incipient stage, while exposed to the atmosphere, weather away by the gradual truncation of the angles, or by the rounding of the contour, through the solvent action of rain, through the action of heat and cold or frost; or again in consequence of particles of sand being driven against them. These same pebbles in a river would possess quite distinct forms, because of the different action of flowing water charged with sand, silt, small stones, etc.; or again, in a glacier, would assume entirely new shapes. The same pebble may at different periods of its career be shaped in many ways by various agencies, and even assume similar forms at recurrent stages of its career, should similar conditions recur.

The regular forms of some pebbles are altered by many causes. A well-rounded pebble becomes fractured and is broken into irregular fragments through other pebbles striking it, or through striking other pebbles or the rocky bed or sides of a stream, or in passing over waterfalls (Plate 12, Fig. 2, and Plate 27, Fig. 2). Such an alteration in form affects the ultimate shape of the pebble. Joints and fissures also may cause a well-rounded pebble to split into an irregular shape. When well-rounded pebbles are exposed to the atmosphere, frost may shatter them again into angular fragments. A conglomerate may have its pebbles ground flat on one side through glacial action, and these pebbles, when freed, will wear away according to their altered form. Bush fires split pebbles up into angular pieces. Vegetation also does this occasionally. Pebbles that are freed by the melting of the ice at the end of a glacier frequently strike the rocky floor with great violence, and some are broken into fragments. During movements in the rock masses (faulting, etc.), well-rounded pebbles in conglomerates are broken across. In some cases the movement is only sufficient to fracture the pebbles (Plate 14, Fig. 3), but in other cases the different portions of a pebble are separated widely. In some instances sand and silt in running water not only shape the pebbles but give a fine polish to them. This is the case at Griquatown, South Africa, where a number of jasper chipped axes and jasper pebbles have had a very high polish imparted to them in a spring (Plate 15, Fig. 2). The secret of this unusual finish appears to be that the fine sand in the spring which has done the work consists of minute rounded and polished grains of chalcedony.

CHAPTER III.

MATERIAL OF PEBBLES.

Nearly all varieties of rocks and minerals—Igneous rocks—Sedimentary rocks—Metamorphic rocks—Native metals—Ores—Meteorites—Ornamental stones—Precious stones—Crystals—Hydrocarbons—Wood—Other organic materials.

In one locality or another probably every variety of rock and mineral occurs as pebbles, except such as decompose or dissolve too readily. Among the crystalline rocks, pebbles of granite, syenite, diorite, porphyry, diabase, dolerite, etc., are common. The older varieties of diabase (amygdaloidal porphyritic, etc.) occurring along the course of the Vaal River, South Africa, have contributed abundance of pebbles to the drifts, as well as amygdules of agate, chalcedony and jasper. These latter have become well-rounded and polished in many cases, and are generally of small size.

The newer basaltic flows that cap the Drakensberg Range, South Africa, are also in part amygdaloidal (Plate 17, Figs. 3 and 4), and the chalcedony and other amygdules in the Vaal River gravels are mostly derived from the wearing down of these and similar rocks. Pebbles of basalt (Plate 67, Fig. 2), andesite (Plate 51, Fig. 2), rhyolite (Plate 31, Figs. 1 and 2), trachyte, obsidian (Plate 17, Fig. 5), pearlstone, tuff, scoria and pumice abound in volcanic regions, such as the Hauraki Peninsula, North Island of New Zealand. Pebbles of sinter occur in the hot springs at Rotorua in the same island. On the beaches of Madeira and the Canary Islands very well-rounded pebbles of basalt occur that are used for paving the streets of the towns.

Pumice pebbles abound in parts of the course of the

Waikato River, New Zealand. Some of the beaches and banks along the course of this river consist almost entirely of pumice pebbles, that float on the water.

Pebbles of quartzite, chert, jasper, flint, quartz, etc., are met with in abundance. All the varieties of sedimentary rocks, such as conglomerates, sandstones, slates, claystones, mudstones, and limestones are found universally as pebbles. In glaciated pebbles, those that are not too hard and that do not decompose too readily hold the scratches and groovings longest. Very hard material, such as the fine siliceous example from North New South Wales (Plate 52, Fig. 2), and the greenstone pebbles of Greenstone Creek (Plate 75, Fig. 1), West Coast, S. Island of New Zealand, show fine needle-scratches. The limestone pebbles in the glacial deposits of Merthyr Tydfil, in Wales, show the scoring the best, and the claystones in the Derrinal glacial conglomerate, near Bendigo, Australia, exhibit the sharpest and clearest scorings and scratches.

Pebbles of clay and of soft shale are met with. In alluvial gold mining, when clay banks are being sluiced away, the clay balls or pebbles are often troublesome, as they collect the particles of gold and bear them away. In the older sedimentary rocks, as in the slaty conglomerate beds found at Bendigo, Victoria, it is evident that when the dark clay that now forms the slate was deposited, it was in places broken up and re-deposited as pebbles with sand in what is now a conglomerate. Frequent evidence is found among the sedimentary rocks of this kind of re-deposition of soft clayey beds that had not become firm before they were torn up, waterworn, and again laid down. In the coal measures this is common, and the parallel is to be seen in clayey beds being deposited at the present time.

Limestone and marble pebbles occur in regions where these rocks are found. Such pebbles are more readily acted on by atmospheric agencies than most rocks, as any form of acid tends to dissolve the carbonate of lime which is carried off in solution. In many parts of South Africa limestones and dolomites occur in which are many laminae of chert, and where pebbles of this compound rock have been exposed to weathering, the cherty bands project beyond the calcareous portion, because the latter is more readily dissolved and removed (Plate 12, Fig. 3).

Chalk pebbles are plentiful where cliffs of this material are being undermined. Pebbles formed of shell occur on many of the Pacific Islands and elsewhere.

Pebbles of conglomerate are found in newer conglomerate. In such cases pebbles were originally aggregated into a conglomerate, which was then broken down and a pebble formed from a portion of it, and this pebble ultimately was enclosed in another conglomerate, showing how these processes are recurrent.

In conglomerate the pebbles are frequently bound together by lime or magnesia carbonate, clay, sand, silica and oxide of iron, or by a mixture of these, but the chief constituent is usually the pebble portion. Conglomerate beds may be formed of pebbles of but one variety of rock, or may be an aggregate of rocks of great diversity. The pebbles of a conglomerate may be gathered from one particular area, or may be swept together from widely different regions.

Breccias result from the fracturing of the rocks through severe strains. The angular fragments are bound together again by silica, etc. Pebbles of brecciated material are not scarce, and they may be obtained to show all the stages in brecciation, from the first shattering of the rock through great strains (Plate 33, Fig. 2; Plate 34, Fig. 1), and the beginning of thin veins in these fissures (Plate 33, Fig. 3) to the growth of the veinstone, until the original fragments of rock are widely separated from each other (Plate 33, Figs. 1 and 4; Plate 34, Fig. 2).

Metamorphic rocks, such as hornfels, gneiss, schist, etc., are abundantly represented as pebbles. Pebbles occur of these altered rocks that were originally sandstone with quartz veins, but the sandstone has been removed, leaving a skeleton pebble of the quartz veins only (Plate 18, Fig. 1). At Reefton, on the west side of the South Island of New Zealand, there are wide beaches of pebbles along the river course that show every gradation of metamorphism from schist to gneiss, and from gneiss to granitic rock (Plates 39, 40, 41, 42, 43). Some of these metamorphic pebbles are veined with rose quartz, others have curious tortuous veins (Plates 44, 45, 46) that apparently represent particular beds in the original sedimentary rock, which was laid down horizontally, but which has been crumpled and altered to a crystalline schist with veins of felspathic material that have resulted from metasomatic action.

Serpentine pebbles are plentiful near the Lizard, Cornwall, England. Steatite pebbles are of frequent occurrence.

Pebbles of gold "nuggets" (Plate 27, Fig. 4), and "specimens" or pebbles of gold and quartz (Plate 27, Fig. 1) are common in the alluvial gold workings the world over; often these are only water-worn on the upper side. Pebbles of platinum are found in Siberia, of silver in Peru and Mexico, of copper in the Red River, Hudson's Bay, North America, of bismuth at Wombat Creek, Victoria. The ores of iron, lead, gold, silver, tin, antimony, copper, nickel, bismuth, etc., are found as pebbles in the streams that cross the lodes. Well rounded pebbles of tin oxide and of tin oxide and quartz occur in Cornwall and in various parts of Tasmania, Queensland, Victoria and New South Wales. Pebbles of limonite and of manganese oxide are not scarce, and at Hokitiki pebbles of carbonate of manganese also occur.

Meteorites fall singly or in showers, and some of these get into watercourses and become pebbles. They are not more frequently found because they eventually oxidise.

Finely-marked agate pebbles are abundant in some localities (Plate 29, Fig. 1 and Plate 30, Fig. 2). Pebbles of agatiform lode material (Plate 30, Fig. 3) are also met with. The agates of the Vaal River, South Africa, are noticeable for the extreme fineness and delicacy of their markings and the great beauty of the colouring. More beautiful pebbles than those found in the Vaal River associated with the diamond could scarcely exist. In Queensland very handsome agates that have become freed from the matrix are found in the streams. In Labrador pebbles of labradorite are common. At Hokitiki, New Zealand, on the sea beach and in the alluvial deposits at Greenstone Creek, about twenty miles distant, beautifully-rounded pebbles and boulders of jade (nephrite), ranging from sand up to a ton in weight occur. Near Beechworth, Victoria, pebbles of rock crystal, citrine, cairngorm, opaline quartz, jasper, topaz, amethyst, and corundum of purple, blue, grey and brown colours are found. In the Orange and Vaal Rivers, South Africa, handsome pebbles of jasper, agate, chalcedony, bloodstone and rose quartz abound. A remarkable black pebble is also plentiful (Plate 11, Fig. 1). This is of a glossy black colour, and strangely enough, the original rock from which it is derived is one of bluish colour that occurs in the jasper series of Griqualand West, and that appears to have a similar composition to crocidolite. This curious rock occurs in thin layers, often jointed into rectangular pieces. The river action wears off the angles, and gives the pebbles a rounded form, and the colour appears to result from oxidation. The contrast between the flat layers of bluish rock and the well-rounded highly-polished glossy black pebbles is so great that the one would not be accepted as derived from the other, were it not that all the stages of alteration can be seen among these pebbles; they have been classed as of meteoric origin on account of their unusual appearance.

Pebbles of diamond occur in the Vaal River, South Africa, the famous "river stones" (Plate 29, Fig. 2). They show unmistakable evidence of attrition. In Brazil pebbles of diamond occur in well-rounded river drift and in a conglomerate. They are also found in Borneo in river gravels.

In Ceylon, pebbles of the precious catseye or chrysoberyl, of ruby, sapphire in its varieties, spinel, and alexandrite are met with, and some are of great value. In Siam and adjacent countries the ruby and spinel are found associated with river gravels. In Queensland, at Emerald and in the surrounding district, pebbles of sapphire in all its varieties are met with. Rounded crystals nearly one pound in weight have been discovered, but the valuable descriptions are usually much smaller. Small pebbles of zircon, clear and fit to cut as gem stones, are numerous, but sapphires suitable for cutting of yellow, blue, green and purple tints are still more abundant. A very rare and extremely valuable gem is the orange-coloured sapphire, which is found there.

Opals partly or wholly rounded are found in Queensland at the surface, but the splendid harlequin and flame opals have to be dug for. A well-rounded pebble of quartz has been found, which, on breaking across, contained a precious opal as large as a pea in the centre.

Topaz, colourless or of various shades of blue, has been found as pebbles on Flinders Island, Tasmania, and on most of the tin ore workings in Victoria, Queensland, New South Wales, and Tasmania. In the last-named country they were of unusual size, and one was found over 20lb. in weight of a beautiful light blue colour. The deep blue and greatly prized variety has been found occasionally in all these localities. One of the finest was obtained at Vegetable Creek, New South Wales, and weighed about 2oz. before cutting.

Pebbles of saussurite thickly studded with small rubies occur in the surface drifts near Hokitiki, South Island of New Zealand. As these pebbles occur in a glacial drift, they may have been transported from a distant source.

Partly rounded crystals of quartz (Plate 29, Fig. 6), topaz (Plate 29, Fig. 4), sapphire, diamond (Plate 29, Fig. 2), and many other minerals are met with.

Pebbles of coal are of common occurrence where seams of hard coal crop out at the surface. Pebbles of coal from one seam are occasionally included in a later coal seam. Pebbles of coal are found in some conglomerates. On the coast of the N. Island of New Zealand, and in some of the rivers, pebbles of brown coal are met with.

Kerosene shale occurs at Woolgoolga, on the northern coast of New South Wales, as well-rounded pebbles on the beach. These may have resulted from a shipwreck, or may have been derived from a natural source. Kauri gum is washed down the rivers of the North Island of New Zealand, and becomes worn into pebbles that float and are cast up on the sea beach at Tairua and elsewhere. Pebbles of bitumen are floated ashore on the north coast of New Zealand, and at many other places. Charcoal pebbles are formed and float down the rivers where forests prevail. They rest on the sand or stones of the beach, and might ultimately become enclosed in a sandstone or conglomerate. Wood partly mineralised and rounded into pebbles occurs at Mercury Bay, New Zealand. Pebbles of wood are found on many shores, and pebbles of silicified wood are found in the Mitta Mitta River, Victoria, on the Karoo, South Africa, and the world over. Pebbles of wood opal are found in Tasmania, and pebbles of wood altered to precious opal occur at White Cliffs, New South Wales.

Ambergris as pebbles occurs in various parts of the world, such as the West coast of the northern portion of the North Island of New Zealand. Kaipara is especially favoured. Pieces that float in on the waves and are tossed about on the shore have been found that weighed up to 1000 ounces, and as it is worth from a few shillings to over £7 per ounce, it is a very valuable substance. It is a secretion in the sperm whale, and on the death of the whale it floats and is cast up on the shore.

Amber pebbles have been collected and prized from prehistoric times. This resin becomes mineralised, and appears to be an extremely durable material. It is found as pebbles on the Baltic coast, and also in Burmah. Ozokerit pebbles are found at Kangaroo Island, South Australia. Pebbles containing skulls and bones of ancient saurians embedded in septarian nodules occur in the watercourses of the Karroo, South Africa, and coprolites, so largely used as a fertiliser, are found as pebbles in river beds in the United States, in Russia and elsewhere. On the Dogger Bank, England, bones of whales and septaria that have become rounded into pebbles by the action of the sea are also met with. Pebbles containing fossils, both animal and vegetable, are found the world over.

CHAPTER IV.

THE FORMATION OF PEBBLES.

Mechanical Agencies: Heat and cold—Wind—Water—Ice—Volcanic action — Earth movements — Organic agencies — Chemical agencies—Reactions between rock-forming minerals—Australites—Plant agencies—Animal agencies.

There is infinite variety in the methods by which pebbles are produced. The processes are not simple in all cases, for a particular example may owe its existence to a great variety of causes, which at one time or another have acted upon it. Besides the action of heat and cold, which cause jointing and fissuring, the most common agencies at work are air, water and ice in motion, volcanoes in action, the motion of the rocks when folding and faulting is taking place, the effects of plants in their growth, and the action of animals. These are mechanical in their effects. Chemical action also has a great influence in the production of pebbles, such as the effect of the gaseous constituents of the atmosphere, fresh water, salt water, both at high and low temperatures, and the reactions of the constituents of the rocks themselves. Water holding in solution such ingredients as cause change—carbonic acid gas, sulphuric acid, chlorides, sulphates, etc.—and the action of living and dead vegetation, all exercise influence in the forming of pebbles.

Most pebbles were orginally more or less angular fragments of rock. The rock mass, no matter how hard, becomes severed along joint lines, either through contraction from a highly heated original condition or from other forces. Even if not so jointed originally, the action of frost and the sun's rays would split it up, though it were formed of adamant. The forces of expansion and contraction are irresistible, and great domes of hard granite, miles across, have yielded to these forces, and are rent right through their mass by fissures, and the jointed mass is thus prepared for the subsequent further jointing that eventually causes the surface to be slowly, but surely, eaten away. Once the main mass is thus fissured the later work of frost and sun are comparatively easy, and in time pieces become detached that are readily moved. Wherever rock is exposed at the surface, no matter how hard it may be, the various stages are apparent by which portions of the mass become detached.

In dry, hot, or cold regions the alternations of temperature are effective in detaching shells from large rock surfaces, or the edges from angular blocks. The lines of fissures, joints and natural divisional planes are just the lines on which the most energy is exerted. Water fills the fissures, and in freezing it increases in bulk, and in this manner great force is exerted. Along these lines, also, plant life in its more lowly forms exerts its influence. All the various forces appear relentlessly to attack the rock mass, and eventually they prevail. Portions are detached, and these again are split up into smaller pieces.

In rocks exposed to the atmosphere there is a general tendency for the angles to be truncated. The rounded forms of granite tors is an exemplification. Originally these were portions of the solid rock mass; joints divided them into angular blocks. First the edges, and then the sides were removed, until their surfaces became rounded: with pebbles similar results follow on exposure to the amosphere, the angles being first attacked. Many rocks weather away into roughly spheroidal forms in situ, so that great numbers of these form on the hill slopes, and as they reach the rills and creeks they are well on the way to form rounded pebbles, and very little water wear suffices to fashion them into pebbles. The dacite rocks met with in so many places in Victoria supply such rude, more than half-formed, pebbles before they reach running water. Between Upper Ferntree Gully and Sassafras excellent examples occur (Plate 19, Fig. 6). Nodules, again, are so shaped as to require but little wearing down to form well rounded pebbles (Plate 26, Figs. 1 and 3).

Once a fragment has become fully detached from the parent rock, it is more readily acted on because of the more extensive surface that is exposed (Plate 1, Fig. 1). The reduction in size, and the wearing away of the angles and corners proceeds more rapidly. While the surfaces exposed to the atmosphere are losing minute particles, however slowly, erosive action is at work removing the earthy or rocky material in which the fragment rests, and if on a slope it is thus moved lower and lower down by gravitation. All the while its bulk is diminishing by the removal of a portion by splitting, and by the weathering away of other portions, all tending to diminish its size. For a longer or shorter period the incipient pebble is thus acted upon.

All the different actions exerted on pebbles have tended to efface the original angles and to produce a more rounded outline. In this forming of pebbles from the original, pieces of rock-material are being removed, and the pebble becomes smaller and lighter as time proceeds. Exceptionally, pebbles accrete material, and in such cases the matter added to the pebble is most commonly carbonate of lime or oxide of iron.

Pebbles sometimes take vast cycles of time to form; in other cases they are beautifully shaped out of the hardest of rocks in the course of a few weeks or months. Some pebbles formed in pre-Cambrian times have remained locked up in their original beds, or they are just now being exposed again to denuding agencies, and after a little more rounding and polishing they may again be enclosed in a conglomerate for a similar period. Other pebbles equally old have been freed from their original beds, and time after time have been subjected to the action of oceans, rivers, ice, wind, volcanoes, etc., and have experienced the many vicissitudes which may befall a pebble in the course of the ages, and they still survive, though the vast majority have been ground to the finest silt, which is the ultimate goal of all pebbles, and to which some hasten, while others approach but tardily, resting may be in a conglomerate for a vast period, then spending more time in a river bed or on the sea-shore, in a glacier, or resting in a moraine, always wasting, always approaching, however slowly, the inevitable end.

From the time that sedimentary rocks are laid down, the crystalline and metamorphic rocks formed, and igneous rocks intruded, poured out, or ejected, there is a tendency in them to become jointed and fissured, caused by corrugations, folds, and faults, or through earth movements, which fracture the rocks in many cases through enormous thicknesses, as the equilibrium of the earth's crust is being adjusted. In other cases joints are induced by contraction in cooling masses of rock that have been highly heated, as granite and other such rocks. In the natural world there is ceaseless action; either the rock is being compacted and built up, or it is being fissured, weathered, demolished, and removed, and so from the time the process of forming a rock mass is complete the process of breaking it down commences, and pebbles form one stage of the process.

Wherever sand is set in motion by the wind, and it comes in contact with fragments of rock, the angles are removed, and the surfaces become more or less rounded, eroded, and polished, and pebbles result which differ in appearance from those shaped by water. The sand blast is a powerful agent in forming pebbles in all dry, sandy regions. Great areas of such arid country exist in America, Africa, Asia and Australia. Not only in such regions, but on beaches the world over, where sand prevails and the winds are sufficiently powerful to drive the sand grains, the rocks exposed at the surface and the beach-stones above high water-mark bear evidence of sand etching. The effect of myriads of sand grains moved by the wind, and striking rock surface or a pebble, is to be seen in the finely pitted surface that results. The action is quite unlike what takes place when similar sand grains are moved by flowing water. In this case the result is a well rounded, smooth surface, but in the case of the wind-moved sand the grains seem to find out every slight difference in texture and hardness, the result is a peculiarly fine, unevenly pitted surface on the stone subjected to it.

At Wanganui, in the North Island of New Zealand, pebbles of very hard quartzite, well rounded by the action of the sea, are exposed on the beach to the action of the wind blowing from nearly opposite directions at different times. The result is that they have been worn away at the sides in a most remarkable manner (Plate 13, Figs. 2 to 5). The bottom of the pebble is protected as it lies in the sand, and the top also is somewhat protected, but the sides appear to have been fully exposed to the sand blast, and they are cut away accordingly, and in this way record the prevailing direction of the wind. In some cases the pebble has been so far eaten away that not even a vestige of the upper surface remains (Plate 13, Fig. 2). The winds along this part of the coast are exceptionally strong, and then the pebbles have been exposed for a very long period. At Hokianga the pebbles on the beach are wind worn (Plate 13, Fig. 1), but they bear no comparison to the Wanganui examples.

In the central portions of Australia the arid wastes are covered by "gibbers" that lie on the surface, and that have become sand worn from the passing of sand storms over them. Some of these "gibbers" are water-worn stones exposed to wind action (Plate 20, Fig. 1); others are rude pebbles formed by the breaking up of thin beds of hard rock in situ, and their subsequent rounding by the action of sand driven by the wind. Great areas in the interior of Australia have these "gibbers" strewn thickly on their surface, and what with the glare from their polished surfaces in the fierce sunlight, the great heat and the misery of walking on and over such pebbles, travelling becomes a pilgrimage and penance combined, and the pebbles in this case are a torture to men and animals.

Atmospheric causes enter largely into the processes by which pebbles are produced. Heat, cold, frost, rain, the air still or in motion, and even electricity, all help in shaping a pebble from the parent rock. The variations between the maximum temperature in the day time and the minimum at night time, especially in elevated regions, is quite sufficient to rend and disintegrate the hardest rock masses. Even solid granite cannot resist the great strains produced in the mass by this unequal expansion and contraction. During the day time the sun's rays raise the temperature of the exposed rock surface, and for some distance into the mass beneath. At night this heat is rapidly radiated at the surface, and a degree of contraction is quickly produced to correspond even to many degrees below freezing point, while the rock beneath is still expanded by the heat acquired during the day. Later on the cold has penetrated deeply into the rock, and produced corresponding contraction, when the sun again heats the outer surface rapidly. In such a manner strains are set up which are irresistible, and the rock mass is riven, and the grains are disintegrated. The process once begun continues, and results in the division and sub-division of the larger masses, until fragments are reached, from which pebbles are formed. Lightning sometimes assists by the explosive action of water in the rock suddenly raised in temperature by the passage of electricity.

In the Stormberg, Cape Colony, the writer saw, on the top of a mountain, near the Indwe coal mines, masses of Cave Sandstone of great size shattered and hurled from their original position by lightning; smaller blocks and pieces were scattered around for many yards, and these were more readily reduced to still smaller fragments by the elements in consequence.

The rain falling on rocks fills any fissures in them. A frost following congeals the water into ice, and as it expands an irresistible rending force is exerted. Oft repeated the results are stupendous, and mighty masses are torn away, and the constituent particles are wedged apart. Where even but slight effects are produced the repetition of the process achieves much. Slowly but relentlessly the rock mass is fractured by opposing strains, and then broken into smaller and smaller masses. These again have their angles removed, and are ever reduced in size so long as exposed to atmospheric influences.

Hail beats off loose particles from exposed rocks. Waterspouts tear down and quickly rend vast quantities of material from their original position, and in a very rapid manner transport huge blocks of rocks for some miles within an hour in some cases.

One of the principal agents in the formation of pebbles is water in motion. As already explained, rain and frost combine in breaking down the rock masses into angular fragments. The atmosphere removes the angles. Little rills after a rainfall carry sand grains past any stationary body, and in this way some little erosion is effected. By slow stages such little rills remove the soil supporting a piece of rock, and the fragment slips down a little at a time, until eventually it gets into a small water course. Perhaps but once a year, or it might be at much longer intervals, there is a rush of water, and the fragment of rock, now well on its way to become a pebble, is moved always lower and nearer to a stream, and at last it is, in the company of many others like itself, in a water course, where a stream runs for a portion of the year only, and now the fashioning goes on more swiftly, for while the water flows either it is ground against its fellows and the angles are rapidly rounded off, or else, if the stream is not strong enough for this, sand grains are carried along, and each of these tiny teeth scrapes off a proportionately minute quantity of the pebble. Eventually the pebble is hurried down by flood waters into a river, which is perhaps perennially flowing, and the more rounded and more easily moved pebble is swept along, perhaps over a rocky bed, and thus quickly ground, or else it remains for months or years on a beach exposed to sun and air until a rainy season sweeps it further down, and so on until the ocean beach or a lake is reached.

It is surprising how rapidly even beautifully rounded pebbles of extremely hard rocks, such as quartz, can be formed when the conditions are favourable. As an example may be mentioned the fact that in many of the alluvial gold mines of Victoria, Australia, the bottoms of the sluices are lined with rough blocks of quartz. Over these there is a rush of sand and pebbles, and although when laid down the stones may be broken and quite angular, within less than a year, if constantly in use, they become well rounded and smooth. It is therefore possible for an angular stone within a year's time after reaching a river bed to be rounded and ground so as to become a perfectly rounded pebble. In natural rock mills, where the stream is constant, pebbles may be formed with great rapidity.

Besides the rain, the rill, the creek and the river, the lapping of waves on the shores of lakes and tarns is helping on the work of making pebbles, and still more potent is the sea with its boundless shore line along which the manufacture of pebbles is proceeding ceaselessly and at a prodigious rate. The tides help, and so do the mighty waves that dash whole beaches of pebbles up against rocky shores and drag them swirling over the sea bed in their retreat. Where rocky cliffs form the shore line, beach pebbles are dashed forcibly against them, and form a powerful means of undermining and destroying the cliffs. As these crumble and fall into the sea, their fragments in turn are ground and worn until they too become pebbles, with which the cliffs are further battered, and so in endless succession. Then there are the currents induced by storms and wind pressure, and this over the whole shallow sea surface of the globe, so that a very great proportion of pebbles owe their origin to the movements of sea water, and it is not to be forgotten that pebbles are relatively much lighter in salt than in fresh water.

Whole mountain masses are composed of pebbles bound together by sand, lime, silica, ferruginous material, or clay, and generally such aggregations of pebbles are attributed to the ocean, or great lakes. Conglomerate beds cover thousands of square miles, and it is not possible to conceive that any river could have accomplished the work. In South Africa the Dwyka conglomerate covers 120,000 square miles, and it is supposed to have been transported by ice and laid down in fresh water in a great inland lake, and to have been partially levelled and arranged by water.

The action of moving water on pebbles is to wear away the softer and more friable parts first, and this goes on until only the cores of the hardest of the rock remain. In a river course the hardest material is found to have travelled the furthest from its source. The softer rocks quickly disappear, being ground into sand or silt. It matters not how hard the original rock, in time it becomes well rounded. Corundum pebbles found at the Woolshed, near Beechworth, Victoria (Plate 19, Fig. 1), and the sapphire pebbles found at Emerald, in Queensland, are examples (Plate 19, Fig. 5). Even the diamond, the hardest known natural substance, becomes rounded in the gravel of the River Vaal, South Africa (Plate 29, Fig.

2). This rounding of the diamond is due to percussion rather than to abrasion.

Rocky beds of streams must help much to shape the pebbles that are rolled over them, and on the other hand the pebbles must do Titan's work in grinding away the beds of streams. Examples of such work are the valley of Woolshed Creek, Victoria, Australia, and on a grander scale the wearing away of a similar rock (granite) below the Orange River Falls, Bushmanland, South Africa, where miles of the solid rock have been removed to a depth of 300 feet. Other examples are the Blyde River, Transvaal, South Africa, which has cut its way down through hard rock, the channel being only a few feet wide in places.

When pebbles are being moved by water they not only wear away the beds of rivers and the rocks on shore lines, etc., but they also wear one another away. On such a beach as that of Hokitiki, New Zealand, the waves rush in bearing the top layer of beach stones with them, and they grind against each other, and very soon become well rounded, and are ultimately and rapidly ground to silt. In Jersey some of the granite quarries are on the sea shore. The spoil is tipped into the sea, and this angular material is quickly converted into well rounded pebbles (Plate 66, Fig. 6).

In caves and underground rivers pebbles are being formed as well as at the surface. At the Kantoor, Transvaal, South Africa, the gravel of underground streams in sandstone was worked for alluvial gold at a depth of from 20 to 100 feet from the surface.

Nuggets of gold (Plate 27, Fig. 4) and specimens—gold and quartz together—(Plate 27, Figs. 1 and 2) when found in the alluvial drifts are frequently extremely well water-worn, but sometimes on one side only, the other being rough and angular. In such cases the wearing down is caused by the passing of pebbles and sand over the surface of the nugget, for such a piece of gold would not be transported by water very far, and its weight would prevent it from being turned over.

Although the specific gravity of gold itself is so great that water does not transport it far when in the free state, yet when particles of gold are disseminated through pebbles of quartz

(Plate 27, Fig. 2), both together may be easily transported for many miles. In this manner the gold in alluvial leads is transported much further from its source than would otherwise be the case. As the pebbles and boulders carrying the gold are borne down the stream they collide, and in this manner portions are broken and rubbed off and the particles of gold are freed and dropped into the alluvial gutters or leads from which the miner removes the wash-dirt for a thousand feet or more in width in some places, and for miles in length, and washes it to win the golden grains scattered through it.

Pebbles formed by ice action are known to occur as far back in geological history as Triassic or Carboniferous times, and probably they were shaped by this agency ever since the stratified rocks began to form, and they have since continued to be so formed, and are now being extensively produced in the localities where cold temperatures prevail, that is to say, in polar regions, and where the surface rises sufficiently above sea-level, the necessary height varying with the latitude. Wherever they exist, and whatever their age, there are certain features which distinguish pebbles formed by ice action from others.

Some of these pebbles consist of angular pieces of rock, from which splinters have been removed apparently by the pressure of larger or harder stones upon them. Such stones are to be picked out of living glaciers (Plate 56, Fig. 3), and exactly similar stones are to be seen in very ancient glacial deposits (Plate 56, Fig. 2). Others of these pebbles are polished on one side, scratched, striated, scored, grooved, either by moving across other rocks, or by other rocks moving across them. Some are fissured by the great pressure on one side, but not on the other (Plate 54, Figs. 2 and 3). Others, again, especially when formed of such hard rocks as quartz, granite, jasper, quartzite, and similarly hard materials, are polished as well as striated (Plate 52, Fig. 1). Scratched surfaces are among the best proofs of glacial origin (Plate 52, Figs. 1 and 2), especially when these are in diverse directions. Pebbles may be formed, and even thoroughly rounded, before they become subject to glacial influences (Plate 52, Fig. 2; Plate 54, Fig 3). The polishing of very hard materials by glacial action may be the result of the long continued action of silt laden water passing over them.

Although the characteristic features above described distinctly prove that a pebble has been exposed to glacial influences, the absence of such marks does not prove the absence of glacial action. It frequently happens that beautifully rounded as well as less finished pebbles, on which there is neither scratch, groove nor polish to show that they had been subjected to ice action, are met with right in glaciers. In fact, the great mass of material in a moraine is sometimes free from such markings. Again, there are other pebbles which have been shaped and marked in glaciers, but that have subsequently been carried into running streams, and there every trace of their ice moulding has been removed.

In South Africa the Dwyka conglomerate (glacial), considered of fresh water origin, is widely distributed, it extends from the temperate into the tropical zone, and proves how widely glacial conditions prevailed when it was laid down. In Australia the corresponding Derrinal conglomerate is also found over a wide region. In each case the climate of to-day over these same regions differs widely from what it must have been when the glacial conglomerates were forming.

Morainal deposits and great areas of conglomerate are formed by the material first picked up by a glacier and subsequently transported by icebergs; they are proof of the extent to which pebbles are formed and transported by glacial action.

In living glaciers, not only are the processes of facetting (Plate 55, Figs. 1 and 2), scratching (Plate 52, Fig. 2), scoring (Plate 53, Figs. 1 and 2; Plate 54, Figs. 1 and 2), polishing, etc., at work, but usually at the foot of the glacier and beneath its deepest part there is a stream which performs the usual function of wearing down, rounding, and grinding the material brought into it. In such streams vast quantities of well rounded pebbles are produced from stones that were first shaped by ice.

A glacier is a frozen river, the movement of which is incomparably slower than the current in an ordinary stream. Where glaciers exist there are usually pinnacles of rock so precipitous that snow does not cover them, and such surfaces are exposed to extremely low temperatures alternating with comparatively high temperatures when the sun shines directly upon them. The result is that fragments are being constantly detached, and these are caught in the snow at the foot of the precipices, and eventually are picked up by a glacier, or the snow conveying them becomes part of a glacier. The stones and dirt thus brought to the glacier are interspersed through the whole mass of the ice, but in consequence of the upper surface melting streaks of these materials form long morainal lines on its surface. Some of these streaks are in the centre, and some at the sides of the glacier. Avalanches contribute largely both snow and fragments of rock and dirt to the glacier. Branch glaciers contribute such materials to the main one. These glaciers, as they travel onwards and down the valleys, become fissured, either through passing over a drop in the bed or in turning around corners. The fissures commonly gape widely, and down them the loose morainal material on the surface falls, and in this manner rough angular material from the top of a glacier falls to the floor at the bottom, and is then subjected to grinding and rubbing action, which quickly converts it into fairly well rounded pebbles. As the pebbles in the glacier are gripped by solid ice and the glacier moves on, they are like teeth in a gigantic rasp, and wherever they come in contact with the sides or floor of the valley they scrape, groove and scratch the rock, and they themselves are splintered (Plate 56, Figs. 2 and 3), facetted (Plate 55, Figs. 1 and 2), grooved (Plate 54, Fig. 2), striated (Plate 52, Fig. 1), or scratched (Plate 52, Fig. 2). When they reach the bottom of the glacier the tendency both of the pressure exerted by the weight of the ice and of the running stream below is to round them.

As glaciers often cover extensive areas, and as they travel for tens, or, in some cases, scores of miles, their influence in forming pebbles can be realised.

Generally where the glacier terminates there is an accumulation of morainal matter. Close to Lake Dora, near Zeehan, in the W. of Tasmania, these terminal moraines are extensive. At the end of the Rhone Glacier, in Europe, the terminal moraine is insignificant. The stream that issues where the glacier ends carries down the glacial pebbles more or less formed, and rounds and grinds them until every trace of glaciation is removed. Such pebbles may be delivered into a river, and all signs of their origin are obliterated. In high latitudes the glaciers deposit morainal matter on the shore, and the sea wears them into ordinary beach stones; or as glaciated material they may be transported for great distances by icebergs which have become detached from glaciers, the material held in the ice being scattered over wide areas. Well rounded pebbles occur high up in mountainous regions among the morainal matter in, or on, glaciers. Such pebbles are probably contributed by some conglomerate bed. In other cases streams may deliver water worn pebbles on to the ice of a glacier.

Loose fragments in the throats of active volcanoes are being continually moved and rubbed together or against the walls of the crater, and in this manner pebbles and boulders of the rocks present are formed. During eruptions the fragments of rock hurled with terrific force high into the air collide, and by percussion and abrasion they help to round each other. Often such fragments fall back again, and are again hurled forth, with the result that some of them become fairly well rounded and others become quite rounded in form (Plate 19, Figs. 3 and 4). Finally such stones may be shot out clear of the crater, or they remain in the crater or pipe. The Kimberley diamond mines of South Africa are being worked in such volcanic pipes, and in the screenings there are large quantities of well rounded "dry pebbles" formed in the manner described above. Most of these are of dolerite. Other pebbles consist of ecklogite (supposed to be the original diamond matrix), gneiss, schist, granite, etc. Some few of these may have been supplied from the thin layer of Dwyka conglomerate at the base of the shales which now form the surface, but the eclogite was brought up from a much lower region. Pebbles of hard eclogite and others resembling the Kimberley "dry pebbles" are met with under similar conditions near Delegete, New South Wales, Australia. Volcanic pebbles differ from those formed by water, especially as regards the rough surface characteristic of the former, and a certain amount of modified angularity. But for the mining operations at the South African diamond fields, the extent to which these "dry pebbles" prevail in volcanic pipes would not have been suspected. In New Zealand, in the Tairua district, North Island, there are extensive deposits of agglomerate and tuff. Some of the material is fairly rounded, while much is angular. With the other material are pieces of obsidian (moldavites) which have pitted surfaces, and are more or less pebble like in form, that appear to have been hurled up in a viscous condition. These on reaching a water course soon become well rounded. Fragments of transparent grey obsidian (morekanites) were also hurled out, and they too are more or less rounded when they reach a stream. Scoriaceous lava that floats in water occurs abundantly on the sides of old Tertiary craters around Clunes, Victoria, Australia, and other volcanic districts, and pebbles of this may be seen floating down the water channels after a storm.

Among pebbles by no means the least interesting are the remarkable bodies known as Australites or obsidianites. They rightly come under the term pebbles because many of them are water worn, or wind worn into true pebbles (Plate 57, Figs. 9, 10, 11, 12). These are often so much altered from their original forms that it is only by means of examples grading back from the pebble condition to the less altered state, that their connection can be established (Plate 57). Australites are remarkable as regards their substance, their shape, and their distribution. The substance is nearest to obsidian or volcanic glass; generally of greenish or brownish grey colour by transmitted light, and black by reflected light, and on analysis, the constituents prove them to be comparable, though not identical, with massive obsidian found in the islands off the N.E. coast of the North Island of New Zealand, and with obsidian from other parts of the world. Their shapes are unlike any other known natural rock occurrence, and though obscure as regards their relations, they can be classified, and the relations clearly established when a sufficient number of types is studied. Type forms are figured to convey an idea of the original forms of these very symmetrical bodies (Plate 57, Figs. 1, 2, 3, 4). They must, when in a molten condition, have been poised or suspended with equal pressure acting on them from all sides. This must have taken place either in a fluid or gas, at the temperature of at least 1300 degrees F.; such material, if in contact with water, would have been violently disintegrated, and, therefore, it must have been suspended in gas. If so suspended, unless by means of a bubble of obsidian forming a balloon, it is hard to conceive how it could have taken place. That these bodies did not traverse the atmosphere at a high velocity when in a molten or viscous condition is proved by their form, and the presence of the rim or flange that is invariably present when the Australites are in their original shape, and not modified by the loss of the rim or flange. They appear to be the blebs or surplus material that has run to the bottom of glass bubbles blown in the throats of volcanoes in a semi-quiescent condition. The forms consist of circular buttons (Plate 57, Fig. 1; Plate 58, Fig. 2), elongated buttons (Plate 57, Figs. 2 and 3; Plate 58, Fig. 5), and of double ended forms (Plate 57, Fig. 4). Originally the complete object probably consisted of the thin sphere of glass filled with highly heated light gases. Apparently at the bottom of this sphere was the bleb formed by the surplus of material, sometimes quite circular, or with one axis longer than the other, or the dumb-bell form. The bleb consisted of two parts, the centre and the flange or margin (Plate 57, Figs. 1, 2, 3, 4). The centre is the thickest portion—and this part ranges from 2 inches to ¼ of an inch in diameter—(Plate 57, Figs. 5, 6, 7, 8). The centres are usually solid (Plate 58, Fig. 3), but cases occur in which they are hollow spheres (Plate 58, Fig. 16, and Plate 58, Fig. 4). In the first example (National Museum collection, Melbourne), the centre was on the verge of becoming a bubble itself, but its further progress was arrested, and the large centre of the bleb became a hollow sphere. In the specimen 1½ inches in diameter (Plate 58, Fig. 4) the centre is also hollow, but it was an incipient double bubble, a thin glass diaphragm dividing the cavity unequally. Other centres (Plate 58, Figs. 3, 6, 7, 8, 9, 10, 11, 12, 13, 14) are solid, as proved by their specific gravity. Another form, quite distinct, is double ended, called the "dumb bell" form, (Plate 58, Fig. 12). The circular buttons (Plate 57, Fig. 1), the buttons with one axis longer than the other (Plate 57, Fig. 2), and the elongated forms (Plate 57, Fig. 3), were all derived from single bubbles, but such double ended forms were probably derived from double bubbles, such as the form shown in Plate 58, Fig. 4, would have developed into. Forming a flange or margin to the central part is a rim that ranges from ⅙th to ¼ inch in width, thickest where it joins the central portion, and thinner on the outside edge, where it probably joined the thin pellicle of glass that formed the bubble. This flange is generally fluted. It is to be met with completely surrounding the central part in cases where perfect; in other cases only fragments are left, attached to the central portion, or it is entirely removed (Plate 58, Fig. 1), and a mark may show where it formerly existed (Plate 57, Fig. 8; Plate 58, Fig. 3). Originally, then, the perfect and complete object consisted apparently of the central, more or less, spherical portion, the rim or flange, and probably the thin glass bubble to which the margin of the bleb was attached. The upper side, or portion of the bleb originally inside the bubble, is generally somewhat dull, principally as regards the central portion, but the rim is glassy (Plate 57, Figs. 1, 2, 3, 4). The underside or outside of the blebs is generally marked with peculiar glassy ridges (Plate 57, Figs. 1a, 2a, 3a, 4a), and the whole exterior presents a glassy black surface. The ridges may be due to the contraction of the bleb as it changed from the fluid to the solid state. As to the thin glass pellicle, it has disappeared. Such a fragile material would just suffice to float the blebs to their destination, and then it would rapidly crumble away, leaving only the blebs.

The distribution of Australites has always been one of the mysteries connected with them. There are serious difficulties in accepting such theories as that these Australites were hurled through space for several thousands of miles, or that blackfellows had transported them. The meteoric origin attributed to them is unlikely, as the material is much nearer in composition to such matter as volcanoes produce on this earth, than to any substance hitherto recognised as coming from an extra-terrestrial source. As to the geological periods to which these bodies belong, it is certain that they occur in recent formations, and they are also found in auriferous drifts that underlie basaltic flows at Rokewood, so that they may be considered as also of Tertiary age. At Mt. William an example is reported to have been found at a depth of 62 feet from the surface, in Newer Pliocene Tertiary deposits. This implies that from Tertiary right down to recent times the bubbles may have been blown in volcanoes and distributed over a great portion of Australia and in Tasmania. Volcanic activity was great during this period in Australia and New Zealand, whence they may have been derived. Until a careful chart of the sites where they are found is prepared, little can be done to prove the site or sites where they originated. It may have been in New Zealand or in the volcanic districts of Victoria or New South Wales, but those that occur in West Australia must certainly have travelled far from their source, because there are no known volcanoes within a thousand miles or so. About Coolgardie and Kalgoorlie, in West Australia, they are numerous, generally well sand worn, not only without the margin or flange, but often with all traces of this rim obliterated (Plate 57, Figs. 9 and 12). Some of these are met with in the auriferous gravels at Rocky Point, Ararat, up to 18 feet below the surface (Plate 57, Fig. 3). At Mt. William, in the Grampian Range, Victoria, Aus., many were found in the auriferous gravels up to 20 or 30 feet from the surface. In Neale's and Malay Gullies they were particularly abundant in the shallow recent auriferous washdirt. They were only found in the washdirt, and not in the 6 or 7 feet of soil above it. They are in some cases water worn (Plate 58, Fig. 3), or sand worn (Plate 57, Figs, 9, 10, 11, 12). Some of them are slightly rounded in the gravel (Plate 58, Fig. 3), while others show no trace of abrasion (Plate 58, Fig. 15). Some are found that are as bright as though fresh from a glasshouse.

They are found in Tasmania, over the southern part of New South Wales, and as far north as the South Tropic, right across Australia; on the S.E. part of Victoria, throughout the Western Districts of Victoria, and throughout South Australia, in Central Australia, also, to the S. Tropic, and throughout the portion of West Australia south of the tropics. They occur hundreds, or even thousands, of miles from the site of any known volcanoes, as near Kalgoorlie, W. Australia. Generally when found the inner side of the bubble is uppermost, as though the bubble had travelled over the spot and descended just where the bleb is found. The bubble may have become fractured, and in this way a descent was caused; the bleb would then be the part to first reach the ground. No doubt, as the bubble came in contact with rock, sand or soil, the thin portion was shattered, and the bleb left. In some cases the margin is sharp, but more generally the edges are rounded. This is caused by the natural tendency to chip away (Plate 57, Fig. 8), and by the sand wear in other cases, or by water wear (Plate 58, Fig. 3). As glass bubbles driven and dispersed by the wind, their distribution is what might be expected. The glass of which Australites is composed appears to be under strain, for chips appear to have been detached apparently without any outside agency. Most examples show this condition. It is noticeable that those from W. Australia are far less perfect in form than those found in Victoria, and none appear to occur there with flanges.

Pebbles that have probably originated in a volcano, that have navigated the air, possibly crossing vast distances over the land and across seas, and that have then rested on mountain tops, at the surface of the ground, on the plains, in rivers and creek beds, and that have been interred with gold-bearing gravels until the miner has unearthed them, deeply buried under drift material, have certainly enjoyed a romantic existence, not shared by ordinary pebbles.

On the lines of faults where great masses of rock have glided over one another, stray fragments of rock that have been caught between the moving surfaces may be rounded, and thus become pebbles. Pebbles have, in many cases, been reported as occurring in lodes, and no doubt they were formed in this manner, or else were derived from conglomerate beds. After the pebbles were formed by the movements of the opposite walls of a fissure or fault, or were derived from a conglomerate bed, through which the fault passed, the mineral matter of the lode may have been deposited so as to completely enclose them. In some of the cases where pebbles have been found in lodes they may have been washed in from the surface.

In Anglesey, Mr. P. A. Matley has described how bands of quartz and quartzite have been pulled out and broken up into placoids, and eventually formed into pebbles by earth movement.

Beds of rock have become broken into fragments, and as the result of wind action have eventually been partly rounded in situ until they resemble ordinary pebbles. This is exemplified by the "gibbers" of Central Australia.

Vegetation assists in the formation of pebbles in many ways, and often at several stages in the history of a pebble. The growth of lichens and mosses on the parent rock mass undoubtedly assists in the development of the cracks and fissures that are probably inherent in it, but which have become more pronounced in consequence of the irresistible forces exerted by alternate heat and cold. Lichens and mosses which grow along the cracks and fissures slowly wedge away small particles, and their decay causes chemical action by which some of the constituents are decomposed. Then larger forms of vegetation grow along the cracks, and the roots exert more force, until eventually portions of the rock are completely detached. These pieces are still further subdivided, and the vegetation continues to detach small particles, to assist in the rounding of the angles, and to diminish the bulk (Plate 62, Fig. 1; Plate 63, Fig. 2), until they reach a stream, and are rolled over and over, and the lichen or moss is removed. The pebble may subsequently become thoroughly rounded in the bed of a stream, but later on it may have a period of rest on a river bank, and then the lichens will soon establish themselves, and again get a roothold on the stone (Plate 62, Fig. 3; Plate 63, Fig. 1), and the work of disintegration will proceed anew. In the life history of a pebble this process may be many times repeated, sometimes with breaks between that run into aeons of time.

In all climates and at all altitudes, the minute forms of vegetation are at work, assisting in the formation of pebbles or in their destruction. Not only is vegetation actively assisting in the wasting away of these bodies at the surface of the earth, but under water, in rivers, and in the sea, weeds are engaged in carrying on similar disintegrating work. Shrubs, trees, grass, and a great variety of vegetation assist either mechanically or chemically in forming, shaping, and later on in diminishing pebbles. In the South Island of New Zealand, on the W. Coast, lichens are especially noticeable on the pebbles (Plate 62, Fig. 2) which are often entirely covered for a thickness of 2 inches or more with such growths. No matter how hard the rocks, for on well rounded quartz specimens they grow freely (Plate 62, Fig. 4), and even on the surface of corundum they thrive. Some of the lichens are of brilliant reds and yellows, etc.

Sea weeds, by transporting pebbles from the bottom of the sea, where they are not being ground away, to the shore, assist in the forming of pebbles (Plates 59 and 60). On the other hand the roots of trees surround, and sometimes quite enclose, pebbles, and this protects them from being washed into a stream, and from the grinding down that would result (Plate 61, Fig. 2).

On the North Island of New Zealand, all over the Hauraki Peninsula, and elsewhere, small, well rounded and polished pebbles of chalcedony, quartz, chert, jasper, and quartzite, are found strewn over the surface, and disseminated through the surface soil. They occur in the flat country, and also on the hills and mountains, though not so abundantly. They are frequent along the crests of the leading spurs. In their forms and general appearance, as well as in their usually highly polished surfaces, these pebbles differ from such as are usually found in water courses, and that have been water worn. They range in size from 2½ inches in length, and 2 oz. in weight, downwards. Often they occur in little heaps that would weigh 2 to 3 lbs. These are the gizzard stones (Plate 18, Figs. 2 and 3) of moas—extinct wingless birds—and they were used for grinding up the tough twigs of bushes on which these struthious birds fed. When first swallowed the stones were angular and sharp edged, and of the hardest and toughest varieties of rock procurable; but the constant attrition caused by the muscular movements of the powerful gizzards of these birds soon rounded and polished them. When they became smooth and polished they were less effective as mill stones and they appear to have been voided, hence the manner in which they are so widely dispersed. Where a large clump of these stones is found the bird must have died, and as it decayed the gizzard stones remained to mark the spot. Their abundance testifies to the large numbers of these birds that once existed, and to the long period during which they roamed the plains and bush of New Zealand. That these stones are actually gizzard stones is proved by their exact correspondence with the gizzard stones found in situ with the skeletons of moas at many places in the South Island of New Zealand. It is probable that the moas flourished until long after the arrival of the Maoris, and that they were preyed upon, and eventually exterminated by that people.

In the South Island gizzard stones are as abundant as in the North Island. Generally the gizzard stones were obtained within a few miles of where the similar stone occurs in situ, and this implies that these birds confined their wanderings to a limited district.

In the early days of the Thames Gold Field extremely rich well rounded small pebbles of gold and quartz were found on the surface, and these are supposed to have been gizzard stones of the moa. The writer has a small gizzard stone of quartz showing a speck of gold, which he found with a number of other gizzard stones on the E. side of Hauraki Peninsula, New Zealand.

Such birds as the ostrich, emu, cassowary, and many smaller birds, use fragments of hard stone in their gizzards, which are by this means turned into well rounded pebbles. The great Epiornis, of Madagascar, when alive, doubtless used such aids to digestion, and with the fragments of their shells, good sized rounded pebbles should also be found that were used as gizzard stones.

Ordinary domestic fowls pick up fragments of stone, pottery, glass, etc., and in their gizzards these are ground into little pebbles. At the Kimberley Diamond Fields, South

Africa, the poultry frequently swallowed small diamonds, and at the principal hotels such diamonds were the perquisite of the cook. Wild ducks, in Australia, have often been shot, and small nuggets of gold found in their gizzards. Turkeys have also been killed with small nuggets of gold in their gizzards in Victoria, Aus. Between Pilgrim's Rest Gold Field and the Kantoor, E. Transvaal, a fowl was killed that had many well rounded small pebbles of quartz in its gizzard, two of these had specks of gold in them. By searching over their feeding ground, fragments of quartz were found with particles of gold in them, and by still closer search, quartz veins carrying gold and from which the fragments of auriferous quartz were derived. In Gippsland, Victoria, as much as half an ounce of gold in small pieces has been found in the gizzard of a fowl. Both crocodiles and seals use pebbles, but whether these are perfectly rounded when swallowed, or whether they become rounded after swallowing, is not known. They are used by crocodiles for grinding their food, by seals as ballast. (See p. 66.)

Along the sea beaches the Pholades (Plate 23, Fig. 2; Plate 24, Figs. 1 and 2) and other shell fish perforate pebbles and assist to break them down and to shape them. Many other forms of marine life also exert an influence in the formation of pebbles, in some cases protecting them from wear and tear, either partially or wholly, in other cases assisting towards their disintegration. Oysters attach themselves to pebbles and protect certain portions from abrasion, and in this manner the forms of pebbles are modified (Plate 64, Fig. 3). Limpets attach themselves temporarily (Plate 64, Fig. 1), Serpularia act in a similar manner (Plate 64, Fig. 2), as well as Lithophyllum (Plate 64, Fig. 4).

CHAPTER V.

VARIETIES OF PEBBLES.

Showing Texture — Constituents — Bleaching — Staining — Curiously-marked — Enclosing fossils — Strangely-shaped — Glaciated — Distorted — Perforated — Faulted — Artificially-formed — Auriferous gravels and conglomerates.

Variations in pebbles result from differences in composition, in texture, in structure, in manner of weathering, in manner of wear, in conditions under which they are formed, and in chemical influences; the result is that they are formed in great diversity. The composition of pebbles ranges through the varieties of rocks. Texture varies also widely in different pebbles of the same material; a siliceous pebble may be formed of quartz derived from a vein of that mineral; it may be of quartz grit, sand, or even finer siliceous material; or even of a rounded quartz crystal; of jasper, agate, or the fibrous quartz after crocidolite, and so on in the other varieties of texture. In structure pebbles may be jointed, veined, or cleaved. Differences of weathering produce different results on pebbles and on their forms. A pebble may be partly exposed in a conglomerate, and this may be weathered away or decomposed. In the process of formation pebbles are subject to many diverse physical influences, and the chemical agencies at work during the process of formation often materially affect the form and composition of the pebbles.

Some pebbles clearly exhibit interesting structure, as where the remarkable contorted strike lines occur (Plate 21, Fig. 3).

Pebbles showing laminations arising from bedding or other causes and having veins that cross the laminations, occur, and the effect of water wear on these is often curious.

Pebbles show the original contortions of the strata in the rocks they are composed of (Plate 32, Figs. 2 and 3).

Pebbles frequently show the constituents of the rock clearly, such as the hornblende crystals (Plate 21, Fig. 2, and Plate 22, Fig. 2).

It may be noticed that, in a heap of pebbles exposed to the dew at night, some remain quite dry while others become covered with moisture. Slaty pebbles with very fine surfaces appear to be most affected in this way.

Pebbles are often bleached white or grey on the outside through long exposure to the elements (Plate 21, Fig. 1), but this bleaching occurs only on the surface exposed to the weather, and is but skin-deep; the natural colour of the stone shows at a little distance below the surface.

Very commonly pebbles are stained by a thin film of oxide of iron through lying in water which carries iron in solution. In some cases they are stained green by carbonate of copper or black by manganese oxide. Permanent bands of colour through the solid rock from which pebbles have formed are common, and frequently are caused by oxide of iron.

Pebbles are frequently crusted over by oxide of iron, manganese or carbonate of lime, etc. On the sea-shore they become covered by serpula, oysters, and other sea-shells and organisms. On the land mosses and lichens often entirely hide pebbles (Plate 62, Fig. 3). On the West coast of the South Island of New Zealand this occurs. In all climates lichens grow on pebbles (Plate 63, Fig. 1).

Pebbles of agate are occasionally found with remarkable resemblances to frogs' or fishes' heads (Plate 29, Fig. 1). Conglomerate pebbles are sometimes met with in which the fragments outline a grotesque human face (Plate 29, Fig. 5). Other pebbles are lined or banded in a remarkable manner (Plate 28, Fig. 1; Plate 32, Fig. 1); the markings on such pebbles are not easily accounted for, those found on this pebble result from stains that originated in, and spread through the rock mass. The reddish colour extended in coatings that were not truly spherical, but that were fairly parallel to one another. Then the rock was worn into a well rounded pebble, but eccentrically to the colour coats, hence the very puzzling markings in this pebble. Concentric stains in some rocks show how the markings in such a pebble might be formed (Plate 28, Fig. 2).

Pebbles that are exposed to atmospheric changes frequently decay, become soft, and even crack (Plate 20, Fig. 2), while the pebbles of the same material under water close by and protected from atmospheric action are quite sound and hard.

Pebbles enclosing fossils, vegetable and animal, are not uncommon. In England the Crag conglomerate encloses pebbles in which are casts of the valves of shells. These are known as box stones (Plate 65, Figs. 1, 2, 3).

Pebbles worn into the oddest shapes are occasionally found, such as shoes, boots, and resemblances of many other objects. These forms generally result where the rock comprising the pebble is of very uneven hardness or is much veined with quartz. Unusually long pebbles (Plate 10, Figs. 1-5) occur where schist rocks are common, as the grain in the schist is favourable to attrition having more effect on the sides than on the ends.

Glacial pebbles are distinguished from others by their characteristic forms (Plates 52, 53, 54, 55, 56) and by their surfaces being facetted, scratched, grooved or polished.

Some pebbles show slickensides quite plainly, and it is necessary to distinguish them from glaciated pebbles. The scoring on slickensided pebbles is parallel, but is not altogether so on glaciated pebbles.

At Black Rock, near Melbourne, concretions of limonite occur in tertiary sandstone. Some of these are worn by the sea into hollow pebbles (Plate 18, Fig. 4).

Some pebbles have themselves been faulted since they were worn into shape, and while they formed a portion of a conglomerate. Near Prince Albert, Cape Colony, are abundant examples that result from the weathering away of the Dwyka conglomerate (glacial) (Plate 14, Fig. 4). In Tasmania, on the moraines near Lake Dora, very fine examples frequently occur (Plate 14, Fig. 3). The pebbles in this case have been derived from the Devonian conglomerate that caps the mountains of that region, and that have been broken down and transported by ice action and left in large terminal moraines.

The dissevered portions of the pebble are sometimes reunited by a vein of quartz (Plate 14, Fig. 3).

The world over, in the conglomerate beds associated with ancient schists, the pebbles have suffered deformation, in most cases apparently the result of enormous pressure. In some cases the pebbles have become flattened out until they are only perhaps one-half or less of their original thickness, and their breadth has been proportionately widened (Plate 14, Fig. 1). In other cases the pebbles have not been so much flattened as elongated (Plate 14, Fig. 2), or again the pebble is fractured, so that what was originally a hard firm rock is quite shattered (Plate 15, Fig. 1). Near Oudtshoorn, Cape Colony, the pebbles in the schist are flattened, and in Little Namaqualand, South Africa, the pebbles in schistose rocks have been flattened out to such an extent that they are barely recognisable as such. In some cases the effects of strain caused by movements of the rock mass is to crush the pebbles out of all shape. Excellent examples occur near Prince Albert, South Africa, in the Dwyka conglomerate, and also near Lake Dora, Tasmania. Where the beds of conglomerate occur in very old formations, such pebbles are usually found (Plate 14, Fig. 4). The quartz pebbles in the auriferous conglomerate at the surface of the Simmer and Jack mine, Johannesburg, South Africa, are much crushed (Plate 15, Fig. 1).

In some conglomerates the pebbles have in an extraordinary manner become impressed into one another, even though the material is quartz or quartzite. These occur in the Alps, and Professor Judd, of London, has described them from near a great fault in Scotland. Extremely good examples occur at the Red Hill, on the road from Stockdale to Dargo, Victoria, Australia (Plate 16, Fig. 1, 2, 3). The conglomerate is of Devonian age, and the pebbles are seldom more than 4 inches long. Some of them are indented to the extent of over one-eighth of an inch (Plate 16, Fig. 3). Portions of some pebbles are left embedded in others (Plate 16, Fig. 1). The material is hard quartzite, generally of pink colour, and white quartz. Although deep hollows are left in some of the pebbles, there is no raised rim around the edges, as might be expected, and the general symmetry of such pebbles is not interfered with. It is only at certain parts of the conglomerate that these pebbles occur. Close by them are others quite normal and not indented, distorted or crushed. It is not by any means clear why some of the pebbles should be affected in this manner, nor is the process by which the work was accomplished at all apparent. Some of them show a deposition of quartz in the hollows, which has been formed subsequent to their being impressed.

Pebbles are perforated by natural agencies in many ways. A pebble may become fixed in the bed of a stream in such a manner that the current causes sand and small pebbles to continually rotate at one spot, and eventually wear a hole right through it. Such pebbles are very rare. This process is greatly facilitated if the pebble acted on happens to be a concretionary nodule, the interior of which consists of a softer material than the outside shell (Plate 25, Figs. 1 and 2). In such cases, once the outer skin is worn through, the softer interior is rapidly abraded, and the grains of coarse and fine sand whirling round within the cavity at last wear through the hard shell on the other side, and a perforated pebble results (Plate 25, Fig. 2). Such nodules of chert that first became detached from their matrix and that have been subsequently converted into perforated pebbles are not uncommon near Whangarei, North Island of New Zealand. Some of the perforated pebbles derived from such nodules become of the shape of a quoit.

Pebbles of flint in which fossils such as belemnites were embedded, and in which the fossils were replaced by calc-spar or other material softer than flint, and from which the softer mineral has been removed, leaving holes in the flint, are of frequent occurrence in the London basin, on the Cornish coast, and elsewhere (Plate 23, Fig. 1). Perforated pebbles of this kind were used by people of great antiquity in Cornwall and on the Continent as in Belgium.

In some rocks there are certain minerals that decompose more readily than others, and pebbles of such rocks are sometimes found perforated as a result. Pyrites, calc-spar, apatite, zeolites are common instances of soft or readily decomposable minerals that occur in hard rocks, and the holes left by their removal are worn still larger and more rounded by sand in moving water. The original rock may have been vesicular, such as the pipe-amygdaloid, Stromberg, South Africa. The pipes or amygdules are in some cases of calcedony, at others of zeolite, and often they are several inches in length. Such a rock when formed into a pebble may have a hole through it in consequence of the weathering out of the zeolite.

Igneous rocks with vesicles in them when formed into pebbles are often perforated (Plate 67, Fig. 2).

Concretionary action takes place in sandstone by the segregation of limonite, and the wearing of these nodules on the sea beach results in perforated pebbles as at Black Rock, Port Phillip Bay, Victoria, Australia.

Wood becomes perforated in many ways by beetles, grubs, etc. After silicification, if pebbles are formed, they will be perforated. In N.W. Australia eucalyptus wood perforated by teredo and subsequently silicified is abundant on parts of the coast.

Conglomerate and tuff frequently contain portions that are softer than the rest of the material, and when pebbles are formed of them such softer materials sometimes decay and cause perforations.

Pebbles of fairly hard sandstone, tuff, and similar material are drilled by Pholades as on the East coast of the North Island of New Zealand, at Mercury Bay and Waiwera (Plate 24, Figs. 1 and 2). A minute shell of this bivalve drills its way into a pebble and then becomes a prisoner, for it is continually growing and the shell becoming larger, so that it cannot retreat by the way it entered, but it has to revolve and bore an ever larger hole until it breaks through to the other side. On entering the pebble the hole is often not more than one-twelfth of an inch in diameter, but the Pholas grows until the hole where it emerges may be three-quarters of an inch or more across. The Pholas probably revolves so as to induce a current in its tunnel, and by this means obtain food, but the act of revolving also drills the hole. Only the larger end of the shell does the boring, and being alive, the cutting edge grows as fast as it is abraded. On the English coasts the Pholades in a similar manner perforate the rocks and pebbles on the sea shore. At Illabarook, Victoria, Australia, pebbles of Tertiary age bored by these shells occur 50 miles from the present shore, and 600 feet above present sea level.

Limestone is very commonly perforated by the action of rain water on the surface of the rock. Fragments of the limestone thus perforated are washed into creeks and worn into pebbles.

Hollow geodes (potato-stones) and agates become water-worn perforated pebbles.

In limestone of tufaceous character and in limonite, spaces occur that have not been filled with these materials. Pebbles subsequently formed from them are perforated.

In quartz veins, cavities are left during the process of crystallisation (Plate 23, Fig. 3). Jasper and similar material have cavities left during the process of formation, and such spaces are often the cause of perforations in pebbles. Such holes would be irregular at first, but the abrasion of sand in a stream would enlarge and make the hole more regular in form.

Hard siliceous Tertiary beds often have cavities in them caused by the decay of stems of plants, leaves, etc., that were deposited at the same time as the siliceous rock, but that have since been removed. At Aberfeldy, Victoria, such beds occur, and pebbles of this rock would be perforated.

Small perforated pebbles of remarkable character occur at Mt. William, Victoria, and elsewhere in Australia; they are the outer rings or rims of volcanic buttons or Australites (the blebs of volcanic bubbles), and they have become detached from the central portion of the button, and are met with in auriferous alluvial deposits (Plate 58, Fig. 1).

Pebbles of gold (nuggets) are often perforated. This may be caused by the removal of a piece of the quartz, and subsequently sand attrition wearing the hole smooth (Plate 27, Fig. 4).

Rocks of the hardness of steatite are perforated in West Australia by insects or worms, and fragments of these might be worn into perforated pebbles.

Pebbles showing faulting of the original rock are common, and they are most instructive (Plates 49, 50, 51). They teach that faulting is of so complicated a nature that no rules can ever be made to meet all cases, and that the apparent movement is frequently altogether different from the actual lines of movement, and sometimes at right angles to it. They teach also that faulting often implies a multiplicity of movements or oscillations to and fro until equilibrium was again established. The complications that may arise in faulting are better studied in pebbles than in models, or in the rock masses.

On the Blauwberg beach, near Cape Town, pebbles of metamorphic sandstone are found that very clearly show one system of quartz veins faulted and dislocated by a later system of felspathic veins (Plate 49, Fig. 2). In New Zealand, on the W. Coast of the South Island of Hokitiki, Greymouth, and Westport, pebbles showing two or three sets of faulting, and veins of many different ages are common (Plate 50, Plate 51, Fig. 1). At Humphry's Gully, near Hokitiki, andesite pebbles, in a glacial auriferous deposit, exhibit this feature in a remarkable manner. Some show five or more sets of distinct faults in a pebble 6 inches across (Plate 51, Fig. 2). Quartz veins generally fill the faults. These quartz veins exercise an influence in shaping the pebbles.

Although as a rule the faults in such pebbles are filled with quartz veins, cases occur in which the rock is faulted, but not filled with quartz or other mineral. An example is shown from near Bairnsdale, Victoria (Plate 49, Fig. 1).

Pebbles showing metasomatic quartz veins occur (Plate 47, Figs. 1, 2, 3). Pebbles that show quartz veins formed by accretion of silica along fissures are common everywhere (Plate 34, Fig. 1, Plates 48, 49, 50, 51).

Dykes of small size traverse some pebbles. Plate 48, Fig. 3, shows a schist pebble, through which is a dyke of eurite and also a quartz vein at the side of the dyke. It illustrates a frequent occurrence of dykes of dioritic character with auriferous quartz veins along the side, the result of contraction in the dyke material. Such dykes occur in the upper portion of the silurian rocks in Victoria, Australia, and are auriferous.

Pebbles are quite common in coal seams at certain places, as Vereeniging, Orange River Colony, South Africa. In this case they were no doubt brought there in floating ice, as they are ice scratched. In other cases they might be embedded in the wood of the butt of a tree, or be entangled in the roots (Plate 61, Fig. 2), and thus be transported. Still another means by which they may have been carried into their present position is by being attached to the roots of sea-weeds (Plates 59 and 60) or other water plants, or entangled in their leaves.

The Tertiary basalt streams that poured down the valleys and covered the plains of Victoria in some places are studded with quartz and other pebbles, and with boulders of many varieties of rocks, as at Kilmore. At Mt. Greenock, near Clunes, Victoria, the auriferous Tertiary lead was broken through by a volcanic outburst, and the crater of Mt. Greenock formed right over its former course. Similar cases are known elsewhere, and the pebbles become entangled in the flow of basalt. It is quite possible that under such circumstances gold also might be found in basalt.

In many countries stone implements are to be found in the gravels of rivers or watercourses that show abrasive action very distinctly. Some of these, from South Africa, formed of lydianite, show that after they were chipped into shape, used, and cast away, and through the lapse of considerable time a patin formed over the surface, which was in process of being again worn off in the river bed (Plate 66, Figs. 1 and 2).

Certain birds that lay their eggs on the ground match the colouring and markings of contiguous pebbles with their eggs (Plate 22, Figs. 1 and 2.)

Pebbles are in some cases entirely formed by human agency, and in other cases they are partly formed in this manner. Where ball mills or similar appliances are used to reduce quartz vein material to sand, so as to save the gold, pebbles are formed that are extremely well rounded, and they are in some cases produced in less than an hour. In alluvial mining angular fragments of quartz are sometimes used to form the bed of the sluices, and in a few months' time the flowing water, bearing pebbles and sand over the sharp edges of the quartz blocks, wears them down, and rounds them off. Artificial objects of iron, brass, copper and lead under some conditions wear into pebbles in streams.

The hardest rocks, such as granite, basalt, etc., broken into small cubes, and used for macadamising the roads and streets, are often partially or fairly well rounded by the wear of the iron tyres of wheels of vehicles, and horses' iron shoes, that pass over them (Plate 19, Fig. 2). Some of these become loosened, and freshets sweep them into gutters, and then into creeks, so that eventually they become quite rounded pebbles, and thus natural material has been broken out and partly shaped by human agency, and the finishing touches are due to natural causes.

When granite or other rocks are being quarried, and the waste is tipped into the sea, as in Jersey and Guernsey, Channel Islands, or into rivers or streams, highly rounded pebbles are quickly formed that cannot be distinguished from wholly natural ones (Plate 66, Fig. 6). Where breakwaters are pushed out from the shore into the sea, as at Cape Town, South Africa, the waves and currents rapidly convert the angular fragments and blocks tipped into the sea into beautifully rounded boulders and pebbles, and this is accomplished within a few months on the sites fully exposed to wave action, although the rocks so fashioned are intensely hard altered sediments (hornfels, etc.).

Again, other pebbles are formed of artificial material, such as concrete, in which angular rock material or pebbles are bound together by cement, or in which rocks or bricks are bound together by lime. Bricks (Plate 66. Fig. 3), tiles, pottery, glass (Plate 66, Figs. 4 and 5), slag, etc., are artificial materials which become ground up on the beaches and in streams into pebbles. On the Marazion beach, Cornwall, all these materials are to be met with ground into pebbles, so that natural materials may be formed into pebbles partly or wholly by human agency or artificial materials may likewise be formed into pebbles, and also partly or wholly by human agency or by natural means.

Natural materials also may be transported for hundreds or thousands of miles, as in the case of ship's ballast, and then may be discharged into the sea or into rivers, and pebbles may be thus formed of material quite alien to the locality where they are found. Or vessels in ballast may be wrecked, and the rocks or pebbles used as ballast become mingled with the local pebbles.

When pebbles are bound together by any material the rock is called conglomerate, or is popularly named "pudding stone" (Plate 35, Figs. 1 and 2; Plate 36, Figs. 1 and 2; Plate 37, Figs. 1, 2, 3). The matrix or cementing material may be lime (Plate 36, Fig. 1), clay (Plate 35, Fig. 2), oxide of iron (Plate 35, Fig. 1), soluble silica, sand, or any combination of these or other substances. Some conglomerate originally formed of pebbles in a sandy matrix now consists of pebbles embedded in white quartz as in the case of Devonian conglomerate pebbles from Glenfalloch, McAllister River, Victoria (Plate 36, Fig. 2). There are quartzite conglomerates, schist conglomerates, slate conglomerates, calcareous conglomerates, arenaceous conglomerates, siliceous conglomerates, and down to clay conglomerates, the pebbles in which can be easily picked out with the fingers. In age conglomerates are to be observed as far back as any semblance of sedimentation can be traced. Usually conglomerates mark the breaks between the formations, occurring at the completion of one period and the beginning of the next. In South Africa there are conglomerates in the Namaqualand schists at the Cango, Cape Colony, the pebbles in which are flattened and drawn out until they can scarcely be recognised. In the Malmsbury Beds there are quartz pebbles distorted and elongated (Plate 14, Fig. 1). At the base of the Table Mountain sandstones, quartz pebbles occur in the quartzite, and in the quartz sandstone. Solitary pebbles are here found (Plate 61, Fig. 1). These pebbles do not appear to be deformed. Later in the geological scale is the Dwyka conglomerate of glacial origin (Plate 35, Fig. 2) that forms such a splendid bench mark, not only in South Africa, but in Australia, where a similar and probably contemporaneous glacial conglomerate occurs at Derrinal, Bacchus Marsh, etc., in Victoria, in Tasmania, in New South Wales, and probably in Queensland. It is represented at Ashford in northern New South Wales below a thick coal seam very much as it exists at Vereeniging, South Africa, and also associated with glossopteris and gangamopteris flora.

Conglomerates occur spread over enormous areas. The Dwyka conglomerate in South Africa ranges from a few hundred feet down to a few feet in thickness. Conglomerates often attain a thickness of 500 to 1000 feet, and sometimes are two or three thousand feet or more thick. The Devonian conglomerate of Victoria and of Tasmania form mountain chains. The material in conglomerate may range from huge rocks a hundred tons or more in weight down to pebbles that grade into sand (Plate 38, Figs. 1, 2, 3). In Eastern Queensland conglomerate bands continue for hundreds of miles in length. Usually conglomerates contain a great variety of pebbles. The stresses in some conglomerates have caused the pebbles to be sheared and displaced (Plate 14, Fig. 3). In the West Coast of Tasmania, and near Prince Albert, in Cape Colony, this feature is well marked: the pebbles are often sheared by a series of step faults on a small scale. Other pebbles are crushed (Plate 14, Fig. 4) or indented (Plate 16, Figs. 1, 2, 3). An interesting conglomerate occurs at Pilgrim's Rest, Transvaal, where about the horizon of the Black Reef are pebbles of well rounded chert bound together with a coarse sandy matrix. Where igneous rocks have influenced this conglomerate the chert is pulverulent, while further away it is quite flinty.

The broad band of Braystones exposed along the east side of Queensland is a conglomerate that performs the great office of collecting and storing water which is tapped by artesian bores in the more parched central portions of Australia.

Where the surface is underlaid by a bed of pebbles, the pebbles form an excellent means of drainage, and houses are much healthier and warmer built over such a bed than over a bed of clay. In London houses built on the gravel areas command higher rents than those on the clay areas. A bed of pebbles below an orchard, a vineyard or a field is also a favourable feature.

These aggregates of pebbles called conglomerates are of great economic value in many cases. The gold bearing conglomerates of Johannesburg, South Africa, contribute largely to the world's supply of that metal. The conglomerates of Lake Superior have produced and are producing vast quantities of copper. Conglomerates in Brazil contributed the world's supply of diamonds until the South African fields were discovered. Even the Kimberley matrix is a variety of volcanic conglomerate. The Tertiary conglomerates of Victoria, Australia, known as cement, have furnished gold in large quantities, and the conglomerated portion of the deep leads, consisting of rounded quartz pebbles bound together by silica, oxide of iron, etc., in that State are richly gold bearing. Conglomerates rich in gold and in tin ore (cassiterite) were worked at the Woolshed, Victoria, and elsewhere in Australia.

Alluvial gravel beds formed by streams and rivers, by the sea or by glacial action, some of them over a thousand feet wide and many miles long, are often of great economic importance. The Recent Post Tertiary and Tertiary gravels of Victoria, Australia, in auriferous areas have given employment to thousands of miners for more than half a century, and have yielded gold to the value of scores of millions sterling. Gold occurs in these gravels from the very surface, and from the outcrop of the reefs or lodes and down to depths of as much as 600 feet below the surface. In some of the deeper mines hundreds of feet of basalt have had to be pierced to reach the rich gold bearing gravels beneath them. The lower ends of these leads have still to be worked, and the great difficulty encountered is the enormous bodies of water that have to be raised, some mines lifting several millions of gallons of water daily. The shallower gravel beds on many of the fields were easily worked, as the depth was but a few feet from the surface, and the yields of gold were in many cases remarkable. Such auriferous gravels have been extensively worked in all the States of Australia, in New Zealand, California, in America, in Siberia and in many other places. In some of the older leads of Victoria the pebbles are formed into a conglomerate of intensely hard character, through which particles of gold are thickly sprinkled. The cementing material appears to be silica. The well rounded nuggets of gold that occur in these leads are themselves pebbles.

It is interesting to note that as are the pebbles in an alluvial lead so is the gold. If the pebbles are well rounded and highly water-worn, so will the gold be; if the pebbles are but half rounded, the gold will be of like character; if the pebbles are angular and sharp, the gold will be hackly, sharp at the edges, and show but little traces of being water worn. Of course an admixture of these different classes is common because branch leads join a main lead or some of the gold in a lead where the pebbles and gold are well rounded may have been locally derived, and therefore not have been subjected to much attrition.

In the Transvaal, South Africa, beds of conglomerate of Palaeozoic age from a few inches to several feet thick are interbedded with sandstone beds at the Rand, Johannesburg. There are many such beds, all more or less auriferous. In 1885 Mr. Struben discovered gold in this conglomerate (named "banket" by the Dutch from its fancied resemblance to almond toffy), with the result that one of the world's principal sources of gold has been developed. From these conglomerate beds an annual yield of gold of between 30 and 40 millions sterling is won, and up to date they have contributed about 225 millions sterling worth of gold. The average yield is from 8 to 10 dwts. of gold per ton of conglomerate. The pebbles in this conglomerate are identical in character with the highly auriferous quartz veins that intersect the far older schists, and that are met with near Jamestown and in the Kaap valley. Probably they were derived from such old auriferous schists. The pebbles themselves do not contain gold, but the material that binds them together does.

Auriferous conglomerates of this character are being worked in the West coast of Africa, and they may be ultimately found to be widely distributed.

Conglomerate formed by pebbles bound together by iron oxide is widely distributed. In the Tertiary leads of the State of Victoria, where they have been long exposed to the atmosphere, as at Wedderburn, what at one time was probably iron pyrites in the bed rock has been dissolved out and altered to limonite, and this firmly binds the quartz pebbles together. In the limonite particles of water-worn gold are sometimes thickly distributed. Similar ferruginous conglomerate occurs at Morrison's Diggings and in many localities the world over. In such cases the limonite has probably been derived from the bed rock underlying the beds of pebbles.

Valuable minerals other than gold occur in gravels. The principal tin supplies of the world have hitherto been obtained from the alluvial deposits, and the Malay Peninsula gravels have yielded enormous wealth in the matter of tin ore. In Australasia also vast quantities have been furnished by the gravels of Victoria, South Australia (Northern Territory), West Australia, Tasmania, New South Wales and Queensland. In Cornwall the stream tin was the original source of supply, and although worked from prehistoric times, yet gravel workings were in progress near Falmouth within the memory of the writer.

Platinum has been worked for in the gravels of Siberia, South America, and Australia. Osmiridium occurs in the gravels of New Zealand, Tasmania, and other places. Thorianite is obtained from Ceylon gravels. Sapphires of many colours are extensively mined in Central Queensland. Hundreds of men are engaged in this industry, and the blue, green, yellow, orange, amethyst and other coloured pebbles of sapphires are the means of providing employment for a large number of lapidaries.

Pebbles of topaz of very large size (up to 20lb. weight) have been found in the gravels of Tasmania. Smaller, but still useful and sometimes valuable deep blue topaz pebbles have been found in the northern portion of New South Wales and in Queensland, and smaller ones in Victoria. In Ceylon, from time immemorial an extensive industry has flourished in searching for pebbles of sapphire, ruby, catseye, etc., in the gravels of the rivers and smaller streams, and in polishing and setting the gem stones discovered.

In Brazil for two centuries the world's demand for diamonds was supplied by washing the gravels of certain districts. Since 1870 the river drifts along the course of the Vaal River have been continuously searched for the glittering diamond pebbles that are there met with associated with most beautifully polished small pebbles. The gravel is loose, and occurs both as an older deposit along the banks of the river, and also in the river bed, where it is subject to removal by every flood. The diamonds are distinctly water-worn, notwithstanding their hardness.

Monazite sand is also obtained from the gravel beds of Brazil, North America and elsewhere.

By means of dredges vast quantities of gravel previously worked are profitably treated for gold, tin ore, etc., in various countries.

In the Lake Superior copper district of America richly cupriferous conglomerate occurs. The metal is in native form, and is extensively mined. Near Roebourne, in West Australia, copper bearing conglomerate also occurs that has not as yet been much explored.

Water either free from other ingredients or charged with other substances, as in the case of salt water, when in contact with pebbles exerts some action on the material of which they are composed. According to the nature of the rock and other conditions, the action of water, either alone or charged with other substances, may be exceedingly slow or very rapid. Such rocks as limestones are readily acted upon, and as they become soluble in the presence of a slight quantity of acid in the water, such rocks are rapidly dissolved away. Some of the minerals of which a pebble is composed may be affected or all may be influenced by the action of water containing other elements in solution.

Frequently pebbles that are exposed to the weather or to which air has access become much more decomposed than the pebblels that are covered by water (Plate 20, Fig. 2). In the Ovens River Valley, Victoria, and in many other places this feature is very noticeable. In other cases the converse is true, and the pebbles exposed to the water are more altered than those exposed to the air. Limestones, dolomite, etc., subjected to water action are dissolved more rapidly than in the air. Chemical action may tend to the breaking down and removal of a portion of a rock, or it may tend to indurate and render more durable the rock exposed to its agency.

Where pebbles consist of two or more materials, one of which is more easily affected by chemical action than the other, unequal weathering takes place, and the results are very marked as in the case of a pebble of dolomite and chert from Griqualand W., S. Africa (Plate 12, Fig. 3). In conglomerate, processes are active in some cases that serve to harden the cementing material, sand, for instance, being altered into quartz (Plate 36, Fig. 2); in other cases to soften and disintegrate it, as atmospheric influences which decompose the hard matrix of the Dwyka conglomerate into clay near Durban, Natal, South Africa. In the Stormberg Range, Cape Colony, a bed of conglomerate covers the principal coal seam in many places. Some quartzite pebbles in this are pitted with angular cavities that look as though formerly occupied by iron pyrites (Plate 15, Fig. 3). Whether the pebbles as originally formed had pyrites in them which has since been removed, or whether these cavities have been formed after they were included in the conglomerate by the growth of iron pyrites into the pebbles and then its removal, is a moot point. The latter appears to be the more probable explanation, for many of the pebbles were broken to see if similar cavities existed inside the quartzite of which they are composed, but none were found. Some of these same pebbles exhibit a crystalline structure on the outside surface, and this appears to be the result of crystalline growth of quartz on to the quartz grains of the pebble, and certainly has been produced since the pebble was enclosed in the conglomerate. Chemical action is beautifully exhibited in a pebble of slate (Plate 27, Fig. 3) from the Caledonia Lead, near Chiltern, Victoria, Australia, which was found by the writer. The pebble is boat-shaped and about 4 inches long. It is split in two on a cleavage, and small rosettes of gold crystals dot the central portion of one of the faces. The gold is arranged to correspond to the outward edge of the pebble, the crystals being larger in the centre and smaller near the edge of the pebble, and has evidently been deposited on this plane from solutions flowing down the lead channel since the pebble was formed and while it was lying in the bed of the lead. The gold was no doubt derived from auriferous reefs at higher levels, where it was dissolved by rain water charged with alkaline material derived from the sediments; this solution acted on the sulphides of iron dissolving the contained gold, and flowing into the bottom of the lead just above where this pebble was found, was re-deposited in the cleavage of this slate pebble.

CHAPTER VI.

TRANSPORT OF PEBBLES.

By Gravitation—Flowing water—Ice—The wind—Earth movements—Volcanic energy—Meteorites—Human agency—Animal agencies—Vegetation.

Blocks of rock and fragments that have become detached from the principal mass on hills and on slopes have a tendency to move down the incline, however slight that incline may be, through the continual erosion going on over the whole earth's surface. As particles of matter are removed from below these fragments they slowly glide downwards, and in some situations the movement is perhaps but slight in a century, or even in a thousand years. On the other hand, where the slopes are highly inclined or precipitous, a fragment or a pebble may descend a mountain side for hundreds or even thousands of feet within a few seconds of time.

Although the descent of material on ordinary slopes does not vividly attract attention, the results actually attained are of great magnitude, and the process is ceaselessly active. The trend of pebbles is nearly always downwards, and as a rule they may safely be taken as occupying a lower position as regards sea-level than the original rock mass which furnished them, for nearly all the processes that assist in forming pebbles require the pebble to move or other material to move about the pebble, and such processes are governed by the laws of gravitation.

Exceptions to this rule are found in cases where volcanic action ejects the material from which pebbles are formed, and also where earth movements and changes in the relative positions of land and water have caused them to be raised perhaps to a higher level even than that occupied by the original rock mass from which they were formed. Pebbles bound together as conglomerates are not infrequently found on the tops of high mountains. Conglomerates have also been found in mines thousands of feet below the present surface. High level Tertiary gravels in Australia and elsewhere attest to mighty changes of level since the pebbles were deposited. In Victoria these gravels occur at elevations up to 4000 feet above the present valley levels, and as they were deposited in the river beds—the lowest surface line—they indicate that since their deposition the whole aspect of the country has been altered by denudation on a vast scale, which has left mountains where valleys stood and created valleys where there were mountains. In the famous auriferous Berry lead of Tertiary age portions of the wash dirt or old river gravel have been raised by faulting several feet above the normal level and sunk below it by over 100 feet since it was laid down.

From the very nature of the case it is evident that every pebble has been transported to a greater or less distance from its parent mass. This distance may range from a few inches to thousands of miles, as in the case of ice-borne material, or in the case of obsidian bubbles which may have been blown and transported for thousands of miles and then the thicker bottom portions of which have become rounded into pebbles, either with drift material in a stream, or by means of sand particles on the surface. As a rule, the further the pebble is transported the smaller it becomes, but this does not always apply to ice-borne material.

Although ice and lava may be the means of transporting pebbles for great distances, these are not the most potent transporting factors. By far the most active agent in transporting pebbles is water in motion as storm-water, rills, rivulets and creeks, rivers, lakes or the sea. As the relative weight of a pebble is less in water than it is in air, it is more readily transported in that medium than in air, and still more readily in salt water than in fresh.

On dry slopes, even in arid regions, a rapid downpour of rain does much execution in moving rocky material. The more violently or the more frequently the storms occur the more rapidly do the fragments travel down the slopes. The quick thawing of snow or ice has a similar effect. Waterspouts act with still greater violence, and move not only such fragments as would form pebbles, but great blocks of rock that are often tons in weight. Storm water serves to move the pieces of rock from the original mass into water courses that may run only periodically, or that are constantly flowing, but subject to rushes of water at intervals. The action of stormwater is erratic and irregular, and pebbles that are one day being hurled violently in a flood are perhaps for months or years high and dry, until another storm moves them on. In some cases a very heavy downpour may strand pebbles in such a position that they would not be moved by ordinary downpours, but only by an unusually violent descent of rain.

By the time a pebble reaches a stream that flows periodically or permanently it is generally more or less rounded; at least the sharp angles have been removed. If the pebble reaches a water channel in which there is only an occasional flow, the progress may still be slow, and the process may be only spasmodic until by easy, perhaps long protracted stages, it reaches a stream where the current is continuous. Unlike the previous stages, the pebble is now being constantly transported. Either it is in a stream where each freshet moves it a little further on, or the stream is strong enough to roll it more rapidly towards a larger creek, thence into a river, and at last it is moved out into the sea, into a lake or perhaps into a marsh.

Streams in flood transport vast quantities of pebbles and boulders, especially where they flow out from mountainous regions, as at Reefton, South Island of New Zealand, or at the head of Kiewa River, Victoria. Even where streams are constant, pebbles that are transported by them may be stranded on the banks or in beaches for long periods. The further the pebbles travel the rounder they become and the easier they are transported. They also become smaller in size, and this again facilitates their transport. Mountain torrents rushing over steep beds hurl great irregular blocks of stone down rocky channels. As the stream flows over a less inclined bed the current is less swift and is less able to move large blocks, but the blocks are more round and require less force to move them. When the river has become sluggish in its current, the pebbles have been thoroughly rounded and have become very much smaller, so that little force is needed to push them along. Streams underground transport pebbles as well as at the surface. At the Kantoor, Transvaal, alluvial gold workings were carried on in caverns in sandstone; both the pebbles and the gold were well rounded, and were transported first by streams at the surface.

In lakes the currents transport and also disperse pebbles.

Currents in the ocean are the means by which great quantities of pebbles are transported and for long distances. The great Chesil Bank, on the English Coast, is a well-known example of this action. Sea currents must be the means of widely dispersing the material brought into the ocean by rivers and icebergs, and widespread conglomerates in general are attributed to marine or lacustrine action.

Along the shores of the ocean there is ceaseless action by waves and tides; by this means pebbles are either removed from the shore or are moved backwards and forwards and ground the one against the other. When waves of unusual height occur, they often cast pebbles high up beyond the reach of the ordinary waves, and there they may remain for considerable periods. Wave action tends to the spreading of pebbles over the sea-bed. The sea constantly wears away existing conglomerate beds and re-distributes the pebbles and arranges them at other localities, or forms fresh pebbles from angular material to be similarly transported and formed into conglomerate beds.

On open exposed shores the waves move the material to and fro, while the currents often transport the pebbles constantly in a set direction.

A stupendous work is accomplished by the waves in gnawing away and removing rocky material around the sea coasts.

Next in importance to moving water as a transporting agent is ice. In regions where very low temperatures prevail the accumulation of snow, or solidified water, becomes more and more compacted by pressure, and is eventually converted into ice and forms a glacier. The ice river flows down the valley for perhaps a few miles, or for many scores of miles. Pebbles and fragments of rock accumulate in and on the glacier, but whether at the bottom or on the surface of the moving ice the pebbles are carried onwards. While a river would quickly transport the pebbles, the ice bears them on but slowly, still the movement is continuous. Just as in a river the pebbles are sometimes thrown high up the banks by some unusual flood, and perhaps left there for a long time, so in the case of a glacier the morainal matter is occasionally left along the sides of the glacier, and considerable periods may elapse before such pebbles are again set in motion. The ice stream on land flows on until the temperature of the air is such as to melt it as fast as it advances. At this spot the glacier ends, and the pebbles in all stages of development are deposited as morainal matter, sometimes to the thickness of hundreds of feet.

In the higher latitudes the great glaciers generally terminate in the sea. Some of these glaciers are 20 miles wide, and at Baffin Bay, in the Arctic regions, the glaciers deliver as much as 2¾ miles of ice per annum into the sea. The glacier often juts out a considerable distance into the ocean before it becomes detached. All this ice contains pebbles distributed through it, so that as a transporting agent, the glaciers of such regions are of no mean importance.

Everywhere glaciers bear within their mass or on their surface pebbles either in the process of forming or well formed. Individual pebbles thoroughly rounded and masses of conglomerate containing such pebbles are a feature in the modern moraines found near Lake Dora, W. Coast of Tasmania. Near this lake is a moraine covering a considerable area to a height of 300 feet, and the whole of this material was transported by ice from the higher mountain tops. The Devonian conglomerate that caps so many of the mountains of this region furnished the material which has been thus transported.

Rock fragments and pebbles which have fallen from the sides of the valley form lateral moraines along the edges of a glacier. Where two glaciers meet, the two inner lateral moraines join to form the medial moraine. Sometimes there are several lines of morainal material on the surface of a glacier. In the Arctic regions (See "Geographical Journal," Vol. XI., p. 362) on the mainland opposite the Pactusoff Islands there is the Ibis glacier, and on its surface, 650 feet above sea level, a medial moraine partly composed of well-rounded pebbles. Where the glaciers have shrunk, as in Switzerland and elsewhere, both the lateral moraines and the terminals attest to the manner in which pebbles are transported by moving ice.

Underneath the glaciers, pieces of rock are transported, both by the action of the ice and of the stream which commonly flows at the bottom of a glacier. The muddy water which usually issues from the end of a glacier attests to the attrition that has taken place, and the pebbles are borne onward by the stream, just as they are by other streams where there is no ice.

When glaciers have to surmount obstacles, in some cases they rise for hundreds of feet, and in this manner pebbles may be raised under certain conditions to a higher level than the original rock from which they were derived.

When glaciers extend into the sea, the masses which break off and float away are known as icebergs, and on and in them are the same materials which the glaciers contained; Arctic voyagers describe how these are often loaded with debris of all kinds, and among this pebbles are well represented. Colonel Fielden, in his descriptions of a visit to the Kara Sea, printed in the "Geographical Journal" for April, 1898, gives a graphic idea of the vast physical results that must ensue from the scattering over the sea floor of such great quantities of material as he saw being dispersed by floating ice. Where the coast has been raised Colonel Fielden describes the great development of boreal beds. In the Antarctic regions also the icebergs are similarly freighted. It is extremely interesting to find that in these regions glacial conglomerates are now being deposited which bear a close resemblance to the widespread Dwyka conglomerate of South Africa, which has been spread over 120,000 square miles, and throughout which glaciated and other pebbles abound. Immediately after the deposition of this conglomerate, formed of material transported from great distances by ice, a period favourable to coal formation followed—the lower coal horizon with glossopteris and gangamopteris flora, as at Vereeniging, where glaciated pebbles probably ice borne occur in the coal seams—and then thousands of feet of fresh water beds known as the Karoo Series, and in which the rich sauroid fossil fauna occurs were laid down.

The Bacchus Marsh or Derrinal conglomerates of Victoria, Australia, with overlying sandstones containing a glossopteris and gangamopteris flora, also appear to have been formed over wide areas and to correspond in many respects with the Dwyka conglomerate of South Africa. The material of these conglomerates has also probably been transported for long distances by floating ice.

Morainal matter such as occurs on every continent, raised sea-bottoms such as are common in the Arctic regions, and terraces like those near Hokitiki, New Zealand, show how extensively pebbles are transported by this means. But the floor of the ocean, both in Arctic and Antarctic regions, could afford still better evidence of the vast quantities of material transported by floating ice. As icebergs are known to float away for thousands of miles from where they originate, the enclosed pebbles are by such means transported for great distances. Since icebergs are dispersers it happens that pebbles from the same original source may be dropped in localities separated by hundreds or thousands of miles, and pebbles gathered at widely-separated localities may be dropped at the same site, at a great distance from where they were picked up.

In countries where the temperature is very low, shore-ice forms, and by this means pebbles from the beach are frozen together when the tide is out, and on its return this ice conglomerate floats out to sea. In rivers a similar action takes place.

Ice as a means of transporting pebbles is an active agent to-day; that it has been equally active back to remote periods in geological history, the ancient glacial conglomerates testify.

Under ordinary circumstances small pebbles are blown about by the wind, but during the fierce cyclones that prevail in tropical regions pebbles of considerable size are moved. When pebbles are mixed with finer material on slopes, the removal of the finer sand, etc., by the wind sets the pebbles rolling. Pebbles enclosed in icebergs are drifted by the wind, as also are pebbles that are entangled in the roots of a tree or in sea-weed. The action of wind on cliffs of conglomerate, especially where sand grains are driven along by it, tends to loosen pebbles and to cause them to drop out. When pebbles are transported as ballast in sailing ships, the wind is the propelling force. The floating bodies of dead seals or other animals that swallow pebbles may be driven by the wind for long distances, and the pebbles are thus transported.

Bodies formed by volcanic agency, such as Australites, may have been transported by the wind for hundreds or thousands of miles, and then have been deposited in such places that in some cases water has worn their sharp edges away, or sand has been the means of rounding some of them when they have been deposited on the surface of the ground.

Pebbles bound together, as in conglomerates, or loose as on beaches, are sometimes raised or depressed, by those sudden movements of the earth's crust known as earthquakes, really by faulting action. More slowly, alterations in their relative levels are brought about by those secular changes that are always and everywhere taking place. Frequently the extent of these movements horizontally amounts to thousands of feet, and vertically to quite as much.

Pebbles, both those formed by the attrition of the fragments of rock shot out of a volcano, and those which have been more or less rounded within the throat of the volcano, and also pebbles derived from conglomerate through which the volcano has broken, are often ejected and hurled for miles from their previous resting place, and in this way a pebble from a conglomerate deep down in the earth may be brought to the surface and laid down in a spot where another and much newer conglomerate is in process of formation. Not only may pebbles be ejected violently from a crater during eruptions, but where volcanoes break through conglomerates, pebbles may become entangled with the lava flows, and by this means be transported to some fresh site. An instance of this occurs at Mt. Greenock, Victoria, where an auriferous lead of Tertiary age is broken through and the pebbles have been caught up in the lava flow. Needless to say that the alluvial gold contained in the wash-dirt was also borne away in the basalt. Pebbles may be, and no doubt were, conveyed for miles in this way. The volcanic pipe of Kimberley diamond mine broke through the Dwyka conglomerate in a similar manner.

Through volcanic energy vast quantities of rock material are transported, and in some cases for long distances, so that rocks originating at a particular site may by this means reach another and distant place. Australites are considered by the author as probably the lower and thicker portions of obsidian bubbles. Once such a glass bubble was set free it would float in the air because of the large surface compared with its weight and on account of the gas within it being lighter than the ordinary atmosphere, and it would be carried high into the air by the ejected gas. The wind would then carry the bubbles over land and sea great distances. Eventually the bubbles would break, either by the glass fracturing from stresses within itself, through rain falling on it, or hailstones breaking the fragile envelope, or from some other cause, and the remains of the bubble descending, some would fall in the sea, others in rivers, or streams, while many would fall on the dry land, on plains, on mountain tops, on rocks or on alluvial soil. Those that fell in streams were borne for longer or shorter distances, and were mingled with the other pebbles that were laid down as gravel beds. Some of these beds have been worked for the gold they contained, and the Australites are found when working for gold at such places as Mt. William, Rokewood, Rocky Point, near Ararat, and Sheep Station Creek, Beechworth, in Victoria, Australia. They are found in auriferous gravels that appear to go back to Tertiary age. At Rokewood, although not found actually under basalt, they are found in gravel that is older than the basalt. Some of the Australites are considerably water-worn (Plate 58, Fig. 3).

Pebbles are sometimes formed from meteorites that have fallen and have then been rounded among other drift material in the beds of streams, or by the agency of wind-borne sand. Pebbles of this character have been transported through space and through the earth's atmosphere with a tremendous velocity, and they possess peculiar interest as visitors belonging to extra-terrestrial regions, and from the manner in which they have reached this globe.

The world over, the several races of man are busily engaged in transporting pebbles to varying distances from their original localities. All the savage races transport pebbles from place to place as they require them for hammers, sinkers, weapons, ornaments, fetishes, etc.

Civilised people transport vast quantities of pebbles, in many cases for very great distances. As ship's ballast, pebbles are obtained by hundreds of tons, conveyed perhaps for thousands of miles to another country, and then discharged in rivers and bays or near the shore. As ballast for railways, pebbles are often transported in large quantities and for considerable distances. For road-making, for concrete work and for other purposes, pebbles are frequently carted or conveyed by boat for long distances.

In mining operations for gold whole hills of gravel are removed and run through sluice boxes so as to gather the grains of gold from the wash-dirt, and then the pebbles and drift are discharged into a river course. In deep alluvial gold mining mile after mile of the gravel from ancient river beds may be raised for hundreds of feet to the present surface, and after the gold is separated, the pebbles are stacked in great heaps that contain hundreds of thousands of tons in many cases. Where sluicing is carried on extensively, the wash is in some cases removed for a depth of hundreds of feet, as at Humphry's Gully, near Hokitiki, South Island of New Zealand, and the pebbles are then run into a river channel, when the water again sets them in motion. Gravel is often transported for great distances by water, or by land, or by both, for use as a covering for garden paths, footpaths, and similar purposes. In metallurgical processes pebbles are transported to place in the bottoms of leaching vats. Flints for use in grinding mills may be carried half way round the world. Gravel beds are largely used for filtering the water supplied to towns, and the material is frequently transported for this purpose.

In ancient times letters to distant countries were engraved on pebbles. Ornamental pebbles were and are transported by both civilised and uncivilised races everywhere. Beautiful pebbles of amethyst, topaz, carnelian, prase or sard were in ancient times engraved on one side and used as seals, and these were widely dispersed from their source of origin.

In New Zealand the many species of moas or extinct struthious birds swallowed fragments of the hardest stones they could find, such as chalcedony, jasper, quartz, or schist, and these were ground together in their gizzards, so as to pulverise the woody twigs, etc., which formed a part of their food (Plate 18, Figs. 2 and 3.) In this way the moas conveyed the stones from one locality to another, and these well-rounded polished pebbles are plentifully strewn over the surface, in both the North and South Islands of New Zealand. Little heaps that would fill a quart measure are found in some places, and these probably mark the sites where the birds died. The moa stones are found on the plain, in the valleys, and on the crests and sides of the hills. They appear to have preferred travelling along the top of the spurs.

In Africa the ostriches use stones for a similar purpose, and in the same manner they disperse the well-rounded small pebbles. When diamonds were first found in South Africa it was supposed that they had been transported from some other region by ostriches. In Australia the emus act in the same way as the ostriches, and it appears that all struthious birds distribute small pebbles in this manner. The great Epiornis of Madagascar must have left pebbles distributed in this way also. Wild ducks and other wild birds have carried small pebbles and sometimes small nuggets of gold or diamonds about in their crops, and this is a means by which pebbles are dispersed. The satin Bower Bird and the spotted Bower Bird of Victoria carry pebbles to their playgrounds.

The amphibious seals have a sac filled with pebbles used apparently for ballasting purposes, and as they are migratory, they would convey pebbles to great distances from their original site. From one locality they may gather pebbles and convey them for hundreds of miles away, and at their death leave them there.

Small pebbles are swallowed by crocodiles for use, as in the case of birds, for bruising food. Pebbles are transported in this way, and curiously enough in some cases there have been found similar small pebbles associated with the fossil remains of extinct saurians.

Mr. L. Bernacchi, of the "Discovery" expedition, describes in the "Red Funnel," a New Zealand periodical, how at Cape Adair, in Antarctica, Pygoscelus adeleae, or the Adelie Penguins, scratch a depression in the old guano and fetch pebbles with their bills and pile them around their nests; this occupies a day or two. Some of the birds pile many hundreds of small pebbles around the nest.

Sea weeds grow on pebbles at the bottom of the sea; as the plants become larger, or as more numerous bladder-like processes form on them, they become so buoyant as to lift the stone off the bottom, and then the tide or current conveys the seaweed with the attached pebble ashore (Plates 59 and 60). In this manner currents can transport pebbles for great distances. When cast ashore on a sandy beach, an explanation is afforded of the way in which isolated pebbles in sandstone may have got there (Plate 61, Fig. 1). This method of transporting pebbles is in action on most sea-coasts. Trees often grow among pebbles; they are sometimes uprooted, washed into rivers, then taken out to sea, and swept by ocean currents across seas and around continents. Entangled in the roots, there are frequently pebbles that are by such means transported to very distant localities. Sometimes the roots grow over a pebble until it becomes quite embedded (Plate 61, Fig. 2), and in such cases the pebble would travel as far as the root containing it, and would only be freed by the decay of the wood. By this and similar means pebbles have been conveyed to remote coral islands in the Pacific Ocean, and the inhabitants have obtained a precious material for their tools, which could not be otherwise found for a radius of hundreds of miles.

CHAPTER VII.

USES OF PEBBLES TO MAN.

As Tools—Weapons—Mealing stones—Sinkers—Weights—Sacred objects—Ornaments—In graves—Juggling—Building—Paving—Filters—Geologically.

From the earliest periods men of all races have availed themselves of pebbles, and have used them in endless ways, and it may be that pebbles have had more to do with the beginning of civilisation than is generally supposed. Pebbles are ubiquitous, and they were doubtless used as the earliest forms of missiles and tools. In size, form and material they presented even to the most primitive people convenient objects for these purposes. Probably the first man that ventured on to the beach used a pebble to open the shell fish on the shore, and even to-day the latest type of humanity does the same thing; so that it is likely that pebbles were first used as hammers (Plate 72, Fig. 1) or missiles (Plate 68, Figs. 2 and 4). Along the coasts where shell fish exist, and where there are or have been primitive races of man, abundant evidences are to be found in their kitchen-middens of the use that was made of pebbles as hammers, and in all museums where such objects are collected, pebble hammers are to be found. The various races that had not discovered the use of metals used such hammers, not only to open shell fish, but also for fashioning other stone implements. As hammers the Kaffir black-smiths of South Africa use pebbles graduated in size according to requirements, the larger sizes weighing perhaps 20 lbs. or more and corresponding to a blacksmith's sledge hammer. They are bound with hide in such a manner as to leave the striking face clear, and two lugs are left so that the striker holds one in each hand and then raises the hammer above his head and brings it down wth great force. The anvil is a suitable boulder. Next to the simple hammer, probably the earliest instrument needed by primitive man was for cutting, just as to-day more civilised men almost always carry a pocket knife. To the earlier man a flake struck by means of a pebble from some hard flinty material, or, still better, from a piece of obsidian, met this need. This flake was sometimes either hafted with a piece of wood, or with resin, or in some similar manner, just as the aboriginals in Central Australia do at this moment. The next most pressing requirement of a primitive man was a chopping instrument, and probably the very first form of an axe was made by selecting a suitably-shaped pebble, one end of which fitted the hand, and the other end was chipped on one side, so as to produce a cutting edge; in this manner an effective chopper was made in a few minutes (Plate 69, Fig. 1). With such a chopper it would be easy to cut up, say, a large kangaroo, so that it could be more easily carried from the hunting ground to the camp. Such primitive choppers were not highly valued, and were doubtless used for the immediate purpose and then cast away, not being worth carrying about. That such simple implements were largely used in some places and cast away, is shown by their great abundance on the Clarence River, northern New South Wales. They are also numerous wherever pebbles are common and the aboriginals have been plentiful. This same pebble hatchet is, no doubt, the forerunner, which has by countless stages and through many centuries of improvement, led up to the highest type of iron and steel axe. The first tool of this type was a suitably shaped pebble, merely chipped on one edge of one end; the next stage was to chip both sides of the one end; then perhaps a pebble that was particularly comfortable for the hand got blunted, and by means of a pointed hard stone it was re-chipped or picked near the edge to bring it back to something like its first sharpness. In the lapse of time another step and a great one would be the discovery that, by rubbing after picking, a sharp edge could be restored (Plate 69, Fig. 2). To get even thus far may have involved whole centuries of time. Once this stage was reached, the further progress was assured. Suitable stones were selected for their hardness, toughness, etc., and were ground, not only to a keen edge, but with the cheeks at such an angle as gave strength, but did not offer too much resistance to the entry of the tool into the bark or wood of trees. At first probably only hand hatchets were used, but by degrees the utility of a haft or handle was discovered, and this was another great step forward. Long afterwards the art of working metals was discovered and improved through a long period of time until bronze was used to make the hatchet. At first the metal was cast to the same form as the useful stone axe which preceded it, but gradually the special qualities possessed by metals, which enabled them to be cast with grooves or holes as readily as without, modified the form which was made suitable for hafting, first of all by exterior grooves, and ultimately by an eye. The stages by which this improvement was evolved were no doubt slow. Later came the more useful and weldable iron axe, which was at first chisel-shaped, the eye being welded in. Still later a piece of steel was inserted for the cutting edge, and last of all the shape has been altered to suit the material and the purpose of the tool, as the latest form of axe shows. There is, therefore, a direct though remote lineage back from the most highly-finished perfect steel axe as made by the American to-day, to the most primitive form of hatchet roughly chipped from a pebble off the beach by means of another pebble.

As missiles pebbles were coeval with their use for hammering and for chopping or cutting. In size, form and weight a pebble beach presents an arsenal of missiles that has been availed of right down the ages. Boys of every race and every clime have instinctively appreciated the advantages of pebbles as missiles. Is there a civilised boy who has not played "Ducks and Drakes" with flat pebbles sent skimming over the surface of river or pond? Just as David with a "pebble from the brook" in his sling slew Goliath, so to-day in New Caledonia the negroid natives of the islands use a simple sling, and also "pebbles from the brook" (Plate 68, Figs. 2 and 4) with such deadly effect that they have killed many a French soldier. By means of pebbles, either with or without a cord attached to them, the Maoris are said to have hunted the moa until it was exterminated (Plate 8, Fig. 2.) Natives of many countries used pebbles attached to a cord for throwing, and in South America pebbles were used for making the bolas. Pebbles were used in the Roman balista and later, covered with lead, as cannon balls.

Fastened to the end of sticks, pebbles have been widely used as weapons, as in New Guinea.

Flat pebbles have been and are being used the world over for grinding grain and seed (Plate 71, Fig. 2); they vary in size according to circumstances. Some of these are carried about as a necessary means of preparing food; others are left at the camping grounds, for they may be large and not suitable for transporting. In South Africa such stones were used by Kaffirs and Hottentots for grinding seed, or grain, and they are to be found in abundance on the sea coast and inland; in fact, wherever men have dwelt. In Australia the blacks carry small stones with them on which to grind grass seeds, and these lower mill stones made from a flat pebble are to be found throughout the continent. These mealing stones are the most primitive form of mills, and from this beginning the latest steel rolling mills have been gradually evolved.

Pebbles are almost universally chosen for mullers, grinders and pestles (Plate 70, Figs. 1, 2, 3; Plate 71, Fig. 1; Plate 72, Fig. 2), and mullers that are not pebbles are quite in the minority. Such stones when not too large are carried about, as they are so frequently in use. They usually range from ½ a pound up to 1 lb. or even 2 lbs. in weight, but for grinding maize, millet, etc., the Kaffirs used long pebbles that weigh up to 6 or 7 lbs., and that require both hands to work them. East of Lydenburg, South Africa, below the Berg, these with other stone implements abound. They were used by the Kaffirs that were massacred, to the number of more than a million, by Moselikatse and his Zulus in his march from Natal to Matabeleland. These mullers have one or more flat sides ground on them, and in some cases so many sides that every trace of the original pebble has been obliterated. Not only for grinding corn and grass seed were such mullers used, but in the North-East of the Transvaal, South Africa, and still further north in Mashonaland, they were used for grinding quartz that had been calcined so as to extract the gold. Hollows are common in the rocks where this process was conducted. In China and India to-day pebbles are commonly used for grinding the ingredients for curries and for other culinary purposes, and in European countries they are still commonly used for grinding paints.

As sinkers for nets and fishing lines, pebbles are in common use in many countries. In New Zealand the Maoris selected stones with high specific gravity for this purpose, such as barytes and limonite, and they took great pains to fashion some pebbles into very useful and elegant sinkers (Plate 74, Fig. 2). Grooves were cut around in one (Plate 73, Fig. 3) or two directions (Plate 74, Fig. 1). Narrow necks were worked on the pebbles, or holes were bored through them, so as to provide the means of fastening them to the nets or lines. They are to be found around the coasts and among the sand dunes in New Zealand. In some cases in this country these sinkers were carved with beautiful curves or with grotesque faces. These sinkers vary greatly in size. Flax strings having a loop were attached to them, and then they were tied to the net or the fishing line. Large long boulders weighing two or three hundredweight corded around and having a loop formed at one end which was fastened to a strong flax cable were formerly used as anchors for their canoes.

In some of the Pacific Islands floats of light wood with short lines and tortoiseshell hook attached are used. To keep them upright in the water, small pebbles are fastened to the end of the float (Plate 68, Figs. 1 and 3).

The dhobies of India use pebbles in washing clothes.

The women of the Knobnose Kaffirs, near Delagoa Bay, in South Africa, use highly polished pebbles for smoothing the floors of their huts.

To within the memory of many still living, bootmakers used a suitable pebble as a lapstone for hammering sole leather on.

Bushmen hunters in South Africa use a pebble with a groove cut on one side for the purpose of straightening the reed shafts of their arrows (Plate 73, Fig. 1). The reed is about the size of a small pencil; it is cut green, and the stone is placed in the fire and heated, the reeds are then rubbed along the groove until they are straightened, and are allowed to cool; they remain quite straight.

An ingenious and remarkable implement used by the Bushman women of South Africa is the digging stick. This was generally made of wild olive wood hardened in the fire and sharpened at one end. A perforated stone weighing 3 or 4 pounds was used to add weight to the stick, which was thrust through the hole and kept in place by a small wooden wedge. Sometimes pebbles were perforated and used for this purpose. (Plate 72, Fig. 3.)

Pebbles were used for weighing from very ancient times by the Egyptians, Greeks, Etruscans, and Romans, and down to recent times in many countries in Europe. In the Truro, British and Brussells Museums examples are to be seen. Their forms and the possibility of securing almost any shape or weight required rendered them valuable for this purpose. The exact weight was obtained by grinding a little off the side of a stone that was over weight. The appellation of the 14 lb. weight as a "stone" is still in use, and no doubt originated through the use of pebbles as weights.

Both Mexicans and Peruvians formerly carved pebbles into the shape of grotesque human forms, many examples of which are shown in the British Museum, and in Carthage pebbles were carved into the grotesque resemblance of a man's face, and were used as idols. The Greeks called such a pebble Caetylus, or "stone with a soul." In Egypt pebbles were similarly used. The art was probably derived from Egyptians, and these were no doubt the predecessors of the Maori Hei Tiki, a grotesque human figure carved out of a greenstone pebble or fragment split from a boulder (Plate 76, Figs. 1, 2, 3). Possibly they indicate a form of ancestor worship. Great labour and great skill must have been expended to produce such a finished example of worked jade (Plate 76, Fig. 3) with no other tools or material than could be obtained among the rocks of the country. It must have required vast patience to split the pebbles of greenstone (Plate 75, Figs. 1 and 2), then to pick them down to near the required size; to then rub them down into shape (Plate 76, Fig. 1) with pieces of sandstone; to drill holes with sharp pieces of chert (Plate 76, Fig. 2), or with a stick, and some sharp sand, and to finish the article with such a fine polish (Plate 76, Fig. 3). These little figures were greatly prized among the Maoris, and were worn either around the neck or as a fastening to their flax or feather cloaks.

In New Caledonia pebbles are used extensively by the natives as fetishes. A fisherman finds a pebble that with a few rough touches of ochre he makes to rudely resemble a fish. This he suspends with cocoa fibre to a tree, bush, or a rafter in his hut to bring him success in fishing; or a pebble selected for some occult reason is hung in his garden to secure a good crop of bananas. Some of these pebbles are smeared with red pigment.

In South Africa the witch doctors frequently include pebbles of some unusual kind among their miscellaneous collection of baboon fingers, bones of the otter, crocodiles' teeth, etc., etc., with which they work their charms. The first large diamond found in South Africa, and known as the "Star of South Africa," was part of the stock in trade of a Hottentot witch-doctor. It was a pebble picked up on the bank of the Vaal River and sold to Mr. Van Niekerk for a waggon and oxen and a flock of sheep. Later it was sold to Lilienfeld Bros., of Hope Town for £11,000. In Gippsland, Victoria, the blacks used pebbles of quartz crystals in their ceremonies, and as a kind of certificate. Pebbles smeared with red ochre are used in some parts of Australia.

In Central Australia small well-rounded pebbles are mounted with emu feathers and are invested with sacred attributes and used in their ceremonies by the natives. A sacred pebble of quartzite smeared with red ochre is used by the Arunta tribe in this region in ceremonies used to ensure a plentiful supply of grubs (Plate 67, Fig. 1).

At Lake Nyassa, Central Africa, witch doctors use pebbles in a gourd as a rattle in their ceremonies.

In India pebbles of fossils are held sacred by the Brahmins.

In some of the islands of the New Hebrides pebbles have a thong attached to them, and the witch doctors on certain occasions fling such a stone in among the throng, and the person struck is immediately seized, sacrificed, roasted and eaten. (Plate 67, Fig. 2.)

Before flint and steel were used to procure fire it is likely that two pebbles of flint or some similar hard material were used to obtain sparks for kindling a fire.

Beautiful forms and colours have always appealed to the instincts of all races of humanity. Even the lowest type of savage is attracted, and as many pebbles possess one or the other or both of these characters combined, they have ever been and they still are utilised as ornaments, not only by the lower types of savages, but by the most highly civilised people. There is still abundant room for a higher appreciation of the very beautiful pebbles to be found in many regions. The Bushman of South Africa, both Hottentot and Kaffir, gathered and treasured these objects. Small pebbles of beautiful colour are frequently worn as ornaments among Europeans, and in India and China pebbles are commonly polished and used as ornaments, or they are manufactured into artistic objects.

Madrepore and other similar pebbles are polished and extensively used as ornaments in England. Delicately tinted quartzite pebbles from the Chesil Bank, south coast of England, are similarly treated.

Painted pebbles are used as paper weights in Jersey. The ancient Hottentot dwellers in the caves along the sea coast of the Knysna, Cape Colony, also painted small figures on pebbles.

Amber pebbles have been used from the earliest times as personal ornaments, either singly or strung together.

Large pebbles, inscribed with cuneiform characters of the time of Sagon I. and of his son Naram Sirr (3800 to 3750 B.C.) were found at Telloh, Mesopotamia, in 1894.

When the young blacks of N.E. New South Wales were initiated into the mysteries of the tribe they were given a pebble. Frequently this was of quartz crystal, and it was apparently in the nature of a credential to show that the owner had been initiated. Those who possessed these stones were loth to show them to anyone, and they regarded the loss of them as a serious matter.

In the graves of early Christians at Rome a white pebble was commonly placed. Mr. Peters, the antiquary of Redruth, Cornwall, informed the writer that in the ancient British graves at Carn Brae, near that town, which he opened (they had been previously disturbed), besides the usual urn, there were from 7 to 20 pebbles of white quartz free from spots or streaks. They ranged from the size of a hazel nut to that of a goose egg. Pebbles of various kinds have been frequently found in graves in many countries. Often pebbles are still used either to cover the grave entirely or arranged in patterns on it.

Kaffirs in South Africa play games by transferring a number of small pebbles from one to another of a set of holes made in the ground. The Maoris of New Zealand use five pebbles as knucklestones. Children of every nation use pebbles as playthings. On the arid banks of the Orange River, South Africa, children of the Dutch Boers place a large pebble on the sand to represent the waggon and pairs of small pebbles for the oxen. In Europe the ground is marked on the pavement into a number of divisions, and a pebble is kicked in proper order from one to the other. Everywhere children are attracted by and value pebbles. It was among a small lot of pebbles collected by a child on the banks of the Orange River, South Africa, that the first diamond was found, and so "out of little things great things grow." The diamond was taken to Grahamstown and recognised by the late Dr. Atherstone as such, and out of that small beginning the great diamond industry has developed.

Diamonds were used in Brazil in the 16th century as counters in card playing. They were obtained from the river banks among the pebbles, and their brilliancy and peculiar forms subsequently led to their recognition as diamonds, and to the development of the diamond industry in South America, and for two centuries the world's requirements were met from this source.

In Ceylon jugglers produce, apparently from their mouths, a series of pebbles that are so large as to barely come out of their mouths. These are ordinary rounded pebbles.

Pebbles were formerly used in the East as bearings for gates and doors. A socket was sunk on the upper side, and in this the end of the gate or door was inserted.

Demosthenes is said to have put pebbles in his mouth when practising oratory, so as to improve his enunciation.

The Chinese grow bulbs of narcissi in a vessel filled with small pebbles and water.

In Kaffir dances, South Africa, both men and women wear girdles made of many little skin pouches in which are small pebbles, and these make a noise on the least movement. Similar noise-making articles are worn on the ankles, knees, and on the head. On the Congo River, W. coast of Africa, pebbles are used in wooden holders as rattles by the witch doctors.

In Bushmanland and Little Namaqualand, South Africa, there are cairns of large size and of great antiquity. They are not made by the Bushmen or Hottentots who now occupy the country, and they have no knowledge of the makers. Possibly the race that occupied Africa before the present inhabitants and that were also spread over Europe, and who have left behind them traces in the pear-shaped flaked stone axes, may have made the cairns. Pebbles were in some cases used for this purpose.

In Australia, New Zealand, the Pacific Islands and many other parts of the world pebbles are used for cooking food. Either heated pebbles are dropped into vessels in which the food is placed with water, and the water thus made to boil, or the stones are heated and the food placed over them, and the whole is then covered up.

As a constituent of concrete, pebbles are used in the construction of harbour works and sea walls, for walls of houses and other buildings, for walls enclosing land, for piers and abutments, for bridges, for pavement, for drains and many other purposes. Where flint pebbles abound in some parts of England they are largely employed in a decorative manner, forming patterns on the outside of the walls and gables of houses and churches.

Throughout Europe pebbles or cobble stones are extensively used for paving streets, courtyards, alleys, stables, etc., and they form a very durable material, but not a comfortable one to walk on. In Madeira and the Canary Islands the streets and road ways are paved with small well-rounded beach pebbles of basalt, and the sleds—for there are no wheeled vehicles in Madeira—glide over them easily. Frequently they are arranged in patterns.

In Cornwall and many other places garden paths are paved with pebbles arranged sometimes in patterns, and the beds are often bordered with pebbles.

The world over pebbles form a convenient and durable material for the construction of roads. Beaches and river beds furnish a supply. In Victoria, Australia, the heaps of quartz pebbles that accumulate from alluvial gold mines in enormous mounds afford a splendid and cheap material for hardening the roads. When properly screened, gravel is one of the best materials for laying down on drives or for footpaths.

Where obtainable, this naturally formed material is used for railway ballast, and the proximity of large and accessible deposits of pebbles along the course of a railway line materially diminishes the cost of construction. The very large stones and the very small are discarded for this purpose.

Where easily obtained, shingle is largely used for ballast in ships, and, if the destination is to a port where such material is scarce, a profit is sometimes made.

Pebbles are very commonly used for filling in trenches for the purpose of draining marshy ground.

Where extensive alluvial gold mining operations are being conducted there are in some cases a mile or more of sluice boxes through which all the gravel and soil have to flow. The wear and tear on the bottom of these boxes is very great, and often quartz pebbles are used to form the floor over which all the material dealt with passes. The interstices between the pebbles serve to arrest the particles of gold, and the quartz pebbles offer a hard surface to the passing material.

Pebbles have been the cause of law suits. At Mt. Greenock the auriferous lead was worked in the early sixties by a co-operative party, and one of them found a bluish coloured topaz in the sluice box. Law proceedings were entered into for the possession of it, and many hundreds of pounds were spent as a result. The stone, which was seen by the writer, was a little more than an ounce in weight, and much flawed. Its intrinsic value was not more than a few shillings.

In the North Sea, off the English Coast, in the beds of many rivers in England and in America and elsewhere, nodules containing phosphatic material that have been rolled, and therefore become pebbles, are dredged for and ground up to fertilise the land.

The Latin term for pebble was calculus, and as pebbles were originally used for adding and subtracting, etc., the term calculation has been evolved.

Pebbles are of incalculable service to the geologist and the student of nature. The pebbles in a river bed indicate the nature of the rocks that may be looked for higher up the stream, or in some of the tributaries. The state of the rounding of the pebbles may imply that certain rocks are close by or at a considerable distance away. Only the harder portions of the rocks can withstand the continuous wear and tear of river action, and a pebble of quartz may survive while the country rock of sandstone, slate, etc., has become entirely ground up, just as in the great auriferous leads at Allendale, Chiltern and Ballarat, in Victoria, the pebbles consist almost exclusively of quartz, because the great mass of country rocks, such as slates and sandstones, have been ground up to sand and silt and carried off, perhaps to the ocean. In many cases the leads can be traced up for miles to their sources. At the beginning there is a general admixture of sandstone, slate, perhaps granite or other crystalline rocks, and some quartz. As the stream is followed down, the proportion of the softer rocks among the pebbles diminishes, and of the quartz increases, until at last nothing remains but the hardest portions of the quartz veins, ground into well-rounded forms. In searching for lodes, pebbles are often of great use, as, for instance, in New Caledonia, where pebbles stained green by nickel ores are to be found in the beds of streams for miles below where the outcrops of nickel-ore exist, and in this manner many of the lodes have been located. On the Whim Well Copper Mines, near Roebourne, North-West Australia, pebbles of green carbonate of copper are to be found in the creek some distance away from where the lode crops out.

Frequently in the alluvial auriferous wash dirt in Victoria pebbles of quartz are found with particles of gold distributed through them; sometimes they are richly studded with coarse gold, and in still other cases large lumps of gold have quartz attached. Such pebbles indicate the nature of the lode from which it has been derived, and in consequence the lodes have been searched for, and sometimes with success. It was through the discovery of gold attached to pieces of quartz in the alluvial gold workings of Victoria that attention was first directed to the quartz reefs as the original source of the alluvial gold.

The forms of pebbles suffice in some cases to determine the nature of a conglomerate, as for instance those of glaciated origin, or again of a volcanic origin. The size, if the rock happens to be a hard one, again may imply, when they are small and thoroughly rounded, a distant source. Impressed, distorted, sheared, elongated, flattened pebbles all bear evidence to physical forces that have been exerted on the rocks in which they were imbedded.

Pebbles often explain the mysteries of their markings, of their structure or of their origin.

As regards faulting, pebbles convey more instruction than diagrams or than can possibly be learnt by studying the features of faults on a large scale, because in a pebble, not only a mere section, but on the back, front, sides and all round the relations are quite plain. Problems that arise where two sets of lodes intersect each other are rendered plain in such pebble examples. They throw much light on difficult and intricate phenomena.

In New Zealand, pebbles at Wanganui that have lain long on the shore are wind-worn to such a degree that they indicate the prevailing directions of the wind.

The presence of pebbles on the top of a hill or mountain is sufficient to indicate that it was a site once covered by water or by ice. On the top of Mt. Fainter, at the head of Kiewa River, Victoria, Australia, which is 6300 feet above sea-level, an old river bed containing well-rounded quartz, schist, gneiss, and granite pebbles has been worked for alluvial gold. A basalt sheet covers it for a thickness of 18 feet, so that what is now one of the highest pinnacles in the country was once the lowest part of a valley. Since the pebbles were deposited in Tertiary times, the Kiewa valley has been deepened over 4000 feet.

Deep below the present surface wide channels are filled with pebbles as in the old alluvial gold leads of Ballarat. Although these are up to 600 feet below the present surface, their presence indicates that where they are found was once the surface, and that a stream of water flowed there, and consequently they occupy an old drainage line.

A single pebble occurring amongst finer material implies that it is aberrant, and that the conditions which brought it there differed from those that brought the rest of the material. The pebble may have been floated over the spot attached to seaweed or to the roots of a tree, or enclosed in ice.

Pebbles in a conglomerate often give a clue to the source from which the material was derived. At Prince Albert, Cape Colony, pebbles of fibrous quartz after crocidolite are found in the Dwyka conglomerate. The nearest known outcrop of this mineral is on the Orange River. A very fine example of agate was found at Yandoit, Victoria, and at Springhurst, Victoria; agates are common in the glacial conglomerate, but no sources from which these could have been originally derived are known in Victoria. On the West coast of the South Island of New Zealand, near Hokitiki, pebbles of propylite traversed by many systems of veins occur in the gold-bearing drifts that appear to have been accumulated by glacial action. The greenstone (nephrite) pebbles and boulders, found near by, have undoubtedly been transported by ice, for they all bear testimony in the shape of fine scratches over most of their surfaces.

Glaciated pebbles in a conglomerate testify to the manner in which its material has been transported.

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Fig. 1.—Angular fragment of quartz from the cap of a lode. This quartz has been merely detached from the outcrop of the vein, and has not been transported even a short distance. All the angles are sharp, and it represents the first stage in the formation of a pebble. Blackman's Lead, Maryborough, Victoria, Aus.

Fig. 2.—Quartz Pebble; angular. It has been transported a short distance only, the edges and angles have been slightly abraded. One mile north of Taradale, Victoria, Aus.

PLATE 2.

Fig. 3.—Quartz Pebble; sub-angular. It has not travelled far. Blackman's Lead, Maryborough, Victoria, Aus.

Fig. 4.—Quartz Pebble; slightly rounded. Maryborough, Victoria, Aus.

PLATE 3.

Fig. 5.—Quartz Pebble; somewhat rounded. Rheola, Victoria, Aus.

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Fig. 8.—Quartz Pebble; rounded. Creswick, Victoria, Aus.

PLATE 5.

Fig. 9.—Quartz Pebbles; well rounded. These have travelled far and have been subjected to much percussion and abrasion to reduce them to their present forms. Cato's Hill, Rheola, Victoria, Aus.

Fig. 10.—Quartz Pebbles; completely rounded. These pebbles have been transported for a very long distance, and they may each be the result of the grinding down of a large block of quartz. Cato's Hill, Rheola, Victoria, Aus.

The above series forms a scale by which the degree of rounding may be described as No. 1 to No. 10 of this scale.

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Fig. 12.—Quartz Pebbles of small size; to show the stages which lead to the ultimate reduction of pebbles to silt. From same locality as Fig. 11.

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Fig. 14.—Quartz Pebbles.—From same locality as Fig. 11.

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These seventeen illustrations give the life history of a pebble, from its commencement as a fragment of rock detached from its matrix, to its reduction to sand grains. There is but one stage more, when these sand grains are ground to silt, which is deposited in beds and indurated to form rocks once more, and the whole process begins again.

PLATE 7.

Fig. 1.—Spherical Pebble of Quartzite. Woolshed, Beechworth, Victoria, Aus.

Fig. 2.—Spherical Pebble of fine Quartzite. Woolshed, Beechworth, Victoria, Aus.

Fig. 3.—Spherical Pebble of Quartzite. Reid's Creek, Beechworth, Victoria, Aus.

PLATE 8.

FIG. 1.—Oval Pebble of Quartzite. Woolshed, Beechworth, Victoria, Aus.

FIG. 2.—Oval Pebble (symmetrical). Fine grained crystalline quartzite. Said to have been used as a missile for killing moas. A thong was attached to it, and in this manner it could be hurled with great force. Manakou, North Island, New Zealand.

FIG. 3.—Ovoid Pebble of Lydianite. It represents an intermediate form between the spherical and cylindrical pebbles. Griquatown, South Africa.

PLATE 9.

FIG. 1.—Flattened spheroidal Pebble of Quartzite. Woolshed, Beechworth, Victoria, Aus.

FIG. 2.—Discoidal Pebble of Schist. Pebbles of this form and material are common on the sea beach at Hokitiki; where very heavy seas break on the shore. They range in size from one-quarter to three-quarters of an inch in thickness, and from one to four inches in diameter. Hokitiki, New Zealand.

FIG. 3.—Cylindrical Pebble of Sandstone. Some varieties of rock have a tendency to wear into such forms. Bairnsdale, Victoria, Aus.

FIG. 4.—Pebble of altered Sandstone, Bright, Victoria. Six and a half inches long.

PLATE 10.

FIG. 1.—Elongated flat Pebble; Schist. Myrtleford, Victoria, Aus. Six inches long.

FIG. 2.—Elongated flat Pebble; Schist. Mitta Mitta River, above junction of Dark River, Victoria, Aus. Ten inches long. View of one side.

FIG. 3.—Same Pebble. View of the edge.

FIG. 4.—Cylindrical Pebble of Sandstone. Myrtleford, Victoria, Aus. Six inches long.

FIG. 5.—Cylindrical Pebble of Schist. Myrtleford, Victoria, Aus. Four and a half inches long.

PLATE 11.

FIG. 1.—Tabular Pebble; glossy black in colour. This pebble was originally a fragment of a thin band of bluish coloured rock that occurs interbedded with the yellow and

brown jasper of the Asbestos Range, Griqualand West. It appears to be a rock containing the constituents of crocidolite, but not in a fibrous condition. It is very hard and tough, and in consequence takes a fine polish. At the same time the constituents of the rock are such that the oxidation produces a glossy black colour. Below Prieska, in the Orange River, extremely well polished examples are to be found. All stages of the alterations are to be seen among the pebbles, ranging from the angular bluish rock to the completely rounded, polished, jet black pebbles. Orange River, just above Prieska, South Africa.

Fig. 2.—Sandstone Pebble; veined with quartz. The shape is influenced by these veins, which, being harder than the rest of the pebble, have resisted attrition better, and they now project above the surface of the sandstone. From Myrtleford, Victoria, Aus.

Fig. 3.—Sandstone Pebble, with quartz vein. Myrtleford, Victoria, Aus.

Fig. 4.—Sandstone Pebble, with quartz veins; which have influenced the shape. Myrtleford, Victoria, Aus.

Fig. 5.—Pebble of Silurian Sandstone, with remains of a quartz vein. The hard quartz has protected a portion of the pebble from wear, and has controlled its form. Warrandyte, Victoria, Aus. Four and three-quarter inches long.

PLATE 12.

Fig. 1.—Pebble of dark Chert, with softer layers. The different hardnesses of the layers are well shown, and abrasive action has caused the present form. Near the junction of the Orange and Vaal Rivers, South Africa.

Fig. 2.—Fragment of Spherical Pebble of Quartzite. The original pebble was thoroughly rounded, but perhaps while bounding down a rocky fall it struck the bottom or side, and this piece was broken off, or else another pebble may have struck it and caused the fracture. The fragment is again somewhat water-worn on the fractured side. This natural fracturing is one of the causes that determine the ultimate forms of pebbles. Wooragee, near Beechworth, Victoria, Aus.

Fig. 3.—Pebble of Limestone and Chert. In the original pebble the surface of the limestone was even with the chert, but since the pebble has been exposed to the atmosphere, the limestone has weathered away more rapidly

than the chert layer, which projects in consequence. Elands Fontein, Griqualand, W. South Africa. Four inches long.

PLATE 13.

Fig 1.—Wind-worn Siliceous Pebble; showing the different effects of the natural sand blast on the harder and softer portions of the pebble. From the beach, Hokianga, North Island, New Zealand.

Fig. 2.—Wind-worn Pebble of Quartzite (Driekanter). Originally this was a well rounded pebble, but as it lay on the surface the sides were cut away by wind driven sand. The wind blew from two nearly opposite prevailing directions, but not equally so, for the one end of the pebble has not been worn away so much as the other. On some of the pebbles the remnant of the upper surface of the original pebble is present, but in this example even that is removed. The bottom of each pebble was protected as it rested on the sand. Wanganui, W. coast, North Island of New Zealand. Presented by Professor Park of Dunedin, N.Z.

Fig. 3.—Same as Fig. 2, but a portion of the top of the original pebble is left. The original pebble was longer and broader than its present representative. Same locality as Fig. 2.

Fig. 4.—Wind worn Pebble. Same locality as Fig. 3.

Fig. 5.—Wind worn Pebble. Same locality as Fig. 3.

PLATE 14.

Fig. 1.—Flattened Pebble of Quartz. A crushed and flattened form of pebble from an ancient conglomerate. Malmsbury Beds, Klapmuts, Cape Colony.

Fig. 2.—Attenuated Pebble of Quartzite; evidently much drawn out since it was formed. From the gold bearing conglomerate at Old Billagoe, Drysdale, New South Wales, Aus.

Fig. 3.—Sheared Pebble of Quartzite from Devonian conglomerate. The overlapping portions are joined together by a vein of crystalline quartz. The moraine, Lake Dora, W. coast of Tasmania. Three and a quarter inches long.

Fig. 4.—Crushed Pebble of Quartzite, Dwyka conglomerate (glacial), Prince Albert, Cape Colony, South Africa.

PLATE 15.

Fig. 1.—Crushed Pebble of Quartz, from the outcrop of the auriferous conglomerate or "banket" ("almond toffy rock") of the Dutch. From these conglomerate beds to the end of 1908 the enormous amount of 62,959,388 oz. of gold, worth over 227 million pounds sterling, has been obtained since 1886. In 1908 the yield was nearly 30 million sterling. The conglomerate beds range from a few inches to many feet in thickness, and are inter-stratified with sandstone, etc. Probably the gold was originally deposited as alluvial gold with the quartz pebbles. Subsequently the gold appears to have been dissolved and to have been then re-deposited with much iron sulphide. The conglomerate together with the associated beds is tilted at varying angles. The quartz pebbles correspond with the auriferous quartz veins occurring in the older schist rock of the Kantoor gold field, Transvaal. Simmer and Jack mine, Johannesburg, South Africa.

Fig. 2.—Polished Pebble of brown Jasper. This pebble has a brilliant gloss produced by the action of fine well rounded grains of chalcedony, which were driven against it by the water of the spring in which it was found. Drie Vogel Fontein, Griquatown, South Africa.

Fig. 3.—Pebble of Quartzite; the surface appears to have been corroded, and holes eaten into it since it was deposited in the conglomerate, that covers the coal seam in many localities at the Stormberg, South Africa. Fossil wood, now altered to haematite, abounds in the conglomerate, and possibly iron pyrites may have filled the cavities in this pebble. The surfaces of some of these siliceous pebbles are etched, and glitter in consequence of the crystalline faces. In other cases the surfaces are deeply corroded, and the original quartz grains of the quartzite are laid bare. It is not certain whether these were rounded pebbles of quartzite and iron pyrites that were together water worn, and from which the pyrites was subsequently removed; or whether the pyrites formed in the pebbles subsequent to their inclusion in the conglomerate. The latter seems the more probable explanation. Modder Bult, Stormberg, South Africa.

PLATE 16.

Fig. 1.—Impressed Pebble; showing the depressions caused by pressure of adjacent pebbles. The end of a quartz pebble remains embedded in the quartzite pebble. Devonian conglomerate. Red Hill, Dargo Rd., Gippsland, Victoria, Aus.

Fig. 2.—Impressed Pebble of Quartzite, showing depressions where other pebbles were forced into it. Red Hill, Dargo Rd., Victoria, Aus.

Fig. 3.—Impressed Pebble of Quartzite, showing deep hollow caused by another pebble being pressed into it. A remarkable feature about these pebbles is that they do not appear to have been deformed; the rim around such a depression is not raised, and the general symmetry of the pebble appears to have been preserved Red Hill, Dargo Rd., Victoria, Aus.

PLATE 17.

Fig. 1.—Pebble of hard Siliceous Rock. The original mass was fractured and re-cemented, and when subsequently reduced to a pebble, the softer cementing material was worn out between the harder portions. Hokianga, North Island, New Zealand.

Fig. 2.—Pebble of Diorite. The original rock was fractured and re-cemented; subsequently the pebble was formed, and the cementing material being softer than the rest of the rock, it has been eroded more rapidly. Jersey, Channel Islands.

Fig. 3.—Pebble of Amygdaloid. Drakensberg volcanic lava with amygdules of zeolite. The volcanic rock was poured out of a volcano, the gases contained in it expanded when it reached the surface, and in consequence the lava was filled with vesicles on cooling and solidifying. Later on water circulated through the rock and decomposed it, dissolving some of its constituents, redepositing some of these as zeolite in the vesicles.

Fig. 4.—Pebble of Amygdaloid. Aliwal N., Cape Colony, South Africa.

Fig. 5.—Obsidian Pebble. This piece of obsidian appears to have been hurled out from a volcano in a plastic state, to have consolidated in the air, and was deposited in an ash bed; subsequently it was washed out of the beds of volcanic ash into the creek. The surface is finely pitted. Obsidian in this form (moldavite) is abundant in the tufaceous beds at this locality. Head of Tairua River, North Island, New Zealand.

PLATE 18.

Fig. 1.—Skeleton Pebble. The original well rounded pebble, consisted of sandstone with quartz veins through it. The sandstone has all been removed, leaving a pebble of the quartz veins only. Blauwberg Beach, Table Bay, Cape Colony, South Africa.

Fig. 2.—Gizzard Pebble, or Moa stone, of chalcedony. At the Thames very rich specimens of gold and quartz were found that had been rounded by the moas' gizzards. Parengarenga, North Island, New Zealand.

Fig. 3.—Gizzard Pebble, or Moa-stone, of quartz. Mercury Bay, North Island, New Zealand.

Fig. 4.—Hollow Pebble of Limonite. A nodule segregated out of the soft Tertiary sandstone. This nodule weathered out on the sea beach, and became water worn. At one end the outer shell wore away, and this allowed of the removal of the soft interior of the nodule. Black Rock, Port Phillip Bay, Victoria.

PLATE 19.

Fig. 1.—Pebble of Corundum. This is one of the hardest substances, and still it is completely rounded. Woolshed, Beechworth, Victoria, Aus.

Fig. 2.—Road Metal of Basalt. This piece of road metal has been partly rounded on the upper side by the percussive and grinding action of the wheels of vehicles and the shoes of horses that have passed over it. Such stones are frequently washed into watercourses, and they soon become well rounded by water action. Park-road, Kew, Victoria, Aus.

Fig. 3.—"Dry Pebble" of Dolerite. Formed in the pipe of a volcano by the attrition and percussion of rock fragments within the pipe. The screenings of the diamond bearing material from the pipe consist largely of such dry pebbles. Kimberley Diamond Mine, South Africa.

Fig. 4.—"Dry Pebble" of Dolerite. From Diamond Mine, Kimberley, South Africa.

Fig. 5.—Sapphire Pebble, not very well rounded. Sapphire is next to the diamond in hardness. Originally this pebble was in an old Tertiary lead, but it was freed and re-deposited in a Recent gravel. The sapphire pebbles attain a size of an inch or more across, and gems of great beauty occur. Orange, yellow, blue, purple, red, brown, white and green colours, and also star sapphires are met with. Emerald Sapphire Mines, Central Queensland, Aus.

FIG. 6.—Core of Dacite, formed by atmospheric weathering. This piece of rock is already of such a form that a very short period in a running stream would suffice to convert it into a well rounded pebble. Such cores are common in this class of rock. One mile from Upper Ferntree Gully Station, on mountain road, Victoria, Australia.

PLATE 20.

FIG. 1.—Quartzite Pebble ("Gibber"). These pebbles strew the surface of the parched interior of Australia, and make walking under a torrid sun a misery to man and beast. Some are formed *in situ* from beds of rock by atmospheric weathering. From Wuntanoorinna Plain, N.W. of Lake Eyre, S. Australia. From Mr. H. J. Grayson, Melbourne University.

FIG. 2.—Cracked Pebble of Sandstone from the high level river gravels of Tertiary age. It is very noticeable in many places that where pebbles are exposed to atmospheric influences they decay far more rapidly than similar materials covered by water. Mitta Mitta Township, Victoria, Aus. Five inches long.

FIG. 3.—Pebble of Kerosene Shale, well rounded by the action of waves. These are abundant along the sea shore in a part of northern N.S. Wales. Possibly they have resulted from the wreck of some ship while carrying shale, or they may have been directly derived from seams of shale. This may be a natural substance artificially transported and naturally shaped. From Woolgoolga, Northern New South Wales. Five inches long.

PLATE 21.

FIG. 1.—Broken Quartzite Pebble. This pebble has lain on the surface for a lengthened period in the position in which it is represented. The long exposure to sun and rain has caused the upper surface to be bleached to a depth represented by the narrow selvage. The under side of the pebble was not so exposed, and has not been bleached. Orbost, Victoria, Australia.

FIG. 2.—Pebble of Hornblende-rock, showing numerous well formed crystals of hornblende. Livingstone Creek, Omeo, Victoria, Aus. Six and a half inches long.

FIG. 3.—Pebble of Satiny Slate. The lines indicate compression along the strike. This unusual form of compression is particularly well shown for many miles around Mitta Mitta Township, Victoria, Aus.

PLATE 22.

Fig. 1.—The Egg of Hæmatopus piligrinosus (sooty oyster catcher): an example of protective mimicry. This bird is found along the coasts of Australia, and lays its eggs on the beach. Such birds lay eggs that resemble the objects around them, and which therefore are likely to escape notice. The next figure is of a pebble which this egg resembles. From Australian coast. Kindly supplied by Mr. Dudley Le Souëf, Melbourne.

Fig. 2.—Pebble of Hornblende rock. Some birds' eggs closely resemble such pebbles. Near Mt. Morgan, Queensland, Aus.

Fig. 3.—Pebble of Dioritic rock, showing a class of pebbles that birds' eggs sometimes resemble. Jersey, Channel Islands.

PLATE 23.

Fig. 1.—Perforated Pebble of Flint. A belemnite, probably replaced by calespar, has been weathered out. Fossils are frequently the cause of perforations in pebbles. These pebbles were used by ancient Britons and sometimes placed in graves: a similar custom existed in Belgium. Even to-day such stones are used in Somersetshire for attaching to keys, etc. Marazion Beach, Cornwall, England.

Fig. 2.—Perforated Pebble of soft Sandstone. The hole was bored by a Pholas, and the pebble has been rounded since. Wenderholm, Waiwera, North Island, New Zealand.

Fig. 3.—Perforated Pebble of Quartz. In this case cavities occurred in the original quartz vein: such cavities are partly filled with crystals. The quartz rock becomes broken down to a pebble, and subsequent sand wear smooths the perforation and enlarges it. Tairua Beach, North Island of New Zealand.

PLATE 24.

Fig. 1.—Perforated Pebble of Grey Volcanic Ash. The shell of a Pholas is shown of the species that drills these holes. The Pholas enters the pebble when very small, perhaps less than an eight of an inch in width. It bores its way in by revolving in its tunnel, which increases in size as the animal grows, until the place of exit may be nearly an inch across. They can alter the course of their burrows, but once inside they are practically prisoners until thy bore right through, because the

burrow widens all the way from where they enter until they escape. Mercury Bay, North Island, New Zealand. Five and a half inches long.

Fig. 2.—Perforated Pebble of soft Sandstone. Holes made by Pholas. Wenderholm, Waiwera, N. Island, New Zealand. Seven inches long.

PLATE 25.

Fig. 1.—Perforated Pebble of Chert. Originally a nodule in the coal bearing sandstone of Tertiary age. Found in a bed of conglomerate of Recent age. Whangarei, North Island, New Zealand.

Fig. 2.—Perforated Pebble of fine siliceous material. It was originally a nodule in sandstone rock. The centre was softer than the outside, and as it lay in a creek bed one side was worn through, then the centre was soon scoured out through the swirling round of pebbles and sand by the stream, and ultimately the under side was also worn through. In the same locality pebbles have been found that have been still further worn until they were of quoit shape. In the conglomerate that often covers the coal measures of the neighbourhood broken portions of such pebbles are not uncommon. Whangarei, North Island of New Zealand. Six and one-half inches long.

PLATE 26.

Fig. 1.—Nodular Pebble. Such siliceous concretions are abundant in the coal bearing beds in soft Tertiary sandstones. They are quite hard and cherty on the outside, and are often much softer in the centre. The nodules are washed into creeks and become pebbles. They range from nearly spherical to discoidal in shape, and some eventually become perforated pebbles. Whangarei, North Island, New Zealand.

Fig. 2.—Hard nodule from soft sandstone of Tertiary age. Broken across to show the interior. The outside is hard chert. The centre is much softer. Whangarei, North Island, New Zealand.

Fig. 3.—Concretionary Pebble (nodule). The material is fine grained brown sandstone. The concretion with a portion of the enclosing rock has become weathered and water worn in a stream. The bedding plane shows well on the specimen. Junction of Vaal and Orange Rivers, South Africa.

PLATE 27.

Fig. 1.—Pebble of Gold bearing Quartz. Coarse and fine particles of gold (which appears white on figure) are distributed right through the pebble, which is well water-worn. About 2 ounces of gold are disseminated through it. Gold worth about 84/- per ounce. From Western Australia.

Fig. 2.—Broken Pebble of Quartz containing particles of gold (which shows white on the figure). This was a well rounded pebble, which was broken by some natural means, and since the fracture the new surfaces have been worn down. Three Mile Creek, Beechworth, Victoria, Aus.

Fig. 3.—Auriferous Pebble of Slate. The pebble is cleaved into two portions, and on the face of the portion shown fine crystals of gold in rosette form are strewn (shown as white spots in the plate). The boundary of the area over which this gold is distributed runs parallel to the outer edges of the pebble, and the crystals of gold are finer near the outside. This gold appears to have been deposited in the cleaved pebble after it was rounded and while it lay in the gutter; the deposition taking place from solutions that ran, or still run along the bottom levels of the lead. This is undoubtedly a case of secondary deposition. Caledonian Lead, Chiltern, Victoria, Aus.

Fig. 4.—Pebble (Nugget) of Gold. This nugget is known as "The Ear." It was found in an alluvial deposit at a depth of 475 feet from the surface on 31/1/82, and it weighed 73 oz. 5 dwts., and was worth £300 sterling. This is an instance of a perforated nugget resulting probably from the removal of a piece of quartz. It is solid gold without any quartz, and is well water worn. Madame Berry Mines, Creswick, Victoria, Aus. Length, five inches.

PLATE 28.

Fig. 1.—Pebble of Quartzite with remarkable markings, due to concentric bands of colour in the original rock. The wearing away has not conformed exactly with the coats of colour. Wooragee, Beechworth, Victoria, Aus.

Fig. 2.—Slate decomposed and showing concentric colour zones in the solid rock. In the centre there may have been a nucleus of iron pyrites, and this during oxidation

caused the colours to spread from that centre through the rock. This serves to illustrate the manner in which such a pebble as (Plate 28, Fig. 1) was marked. Heathcote, Victoria, Aus. Nine inches long.

PLATE 29.

FIG. 1.—Pebbles of Agate and Chalcedony, from river gravel which contains diamonds, garnets, chalcedony, jasper and very finely marked and beautifully coloured agates. Vaal River, near Pniel, Cape Colony, South Africa.

FIG. 2.—Pebble of Diamond. From Vaal River, South Africa.

FIG. 3.—Pebble of Agate: sliced to show its structure. In volcanic rocks cavities are formed by the expansion of contained gases. These cavities remain after the molten rock has cooled; water circulates through it, and these cavities become filled with solutions containing silica, which is deposited in thin concentric coats, sometimes as quartz, at other times as chalcedony. In this example the bottom of the cavity in which the agate was formed is indicated by the horizontal portions of the concentric layers. Each of these horizontal films is thicker than its continuation at the sides and top of the cavity. The coats were first laid down on the walls of the volcanic rock, within the vesicle, and each succeeding layer followed on the last, until the cavity was entirely filled up and the solid agate formed. Conditions occurred that varied the thickness, the composition and the colour of the various layers. Agate Creek, Queensland, Aus.

FIG. 4.—Pebble of Topaz. The crystal has become fairly well rounded, but the faces of the crystal are still well marked. Herberton, North Queensland, Aus.

FIG. 5.—Pebble of Conglomerate; showing a grotesque resemblance to a human face. Apollo Bay, Victoria, Aus.

FIG. 6.—Pebble of Quartz Crystal, water worn. Chinaman's Flat, Beechworth, Victoria, Aus.

PLATE 30.

FIG. 1.—Pebble of Trachyte, showing flow structure. Tairua, North Island, New Zealand.

FIG. 2.—Pebble of Agate; well water worn. Woolshed, Beechworth, Victoria, Aus.

FIG. 3.—Pebble of Quartz Veinstone with agatiform silica on the inner side. Marazion beach, Cornwall, England.

PLATE 31.

Fig. 1.—Pebble of Rhyolite, showing remarkable segregations. Tairua, North Island, New Zealand.

Fig. 2.—Pebble of Rhyolite, showing variolitic segregations. Tairua, North Island, New Zealand.

PLATE 32.

Fig. 1.—Pebble of red Jasper and cherty white silica of igneous origin. The peculiar markings are not the result of faulting, but appear to have formed in the igneous rock in a segregatory manner before it cooled and solidified. Ten miles N.E. of Griquatown, South Africa.

Fig. 2.—Pebble of brown Jasper with magnetic iron in thin layers. The original bedding has been greatly contorted, and the wearing down of the pebble has resulted in this pattern. The thin lines of magnetite are etched below the surface of the jasper. Prieska, South Africa.

Fig. 3.—Pebble of contorted Jasper. The soft clayey material was contorted before it became jasper. Strang Fontein, six miles east of Daniel's Kuil, Griqualand W., South Africa.

PLATE 33.

Fig. 1.—Pebble of fine brecciated Quartzite. The fragments of quartzite are surrounded by a halo of black tourmaline, and the whole is bound together by vein quartz. Valencia Creek, Gippsland, Victoria, Aus.

Fig. 2.—Pebble of Quartzite showing breccia in its first stage. The quartzite is fissured but not displaced to any extent; the fissure is filled by thin veins of limonite. Dwyka conglomerate, Prince Albert, Cape Colony, South Africa. Four inches long.

Fig. 3.—Pebble of brecciated Quartz, veined with red jasper. The quartz was shattered by great pressure, and the jasper in solution was subsequently introduced into all the fissures, and in this manner the loose fragments of quartz have been bound together into a solid rock. Stratford, Victoria, Aus.

Fig. 4.—Pebble of Siliceous Breccia. The grey portion is quartzite, the cementing material dark purplish quartz. From Woolshed Creek, Beechworth, Victoria, Aus. Three and a half inches long.

PLATE 34.

Fig. 1.—Pebble of Sandstone Breccia. The quartz veins have formed in the fissures of the rock. This is an example of quartz veins deposited from solutions filling fissures. Near Mt. Deddick, Gippsland, Victoria, Aus. Five inches long.

Fig. 2.—Pebble of Breccia. Fragments of siliceous crystalline rock are cemented together by black tourmaline. Originally this came from a large lode. Opas Creek, near Marysville, Victoria, Aus. Five inches long.

PLATE 35.

Fig. 1.—Auriferous conglomerate of quartz pebbles bound together by limonite. It is probable that after the pebbles were deposited on the slate and sandstone beds the iron leached out of the underlying rocks and was re-deposited in the overlying pebble bed. The beds below the old leads are commonly bleached (pipe clay bottom of the miners). The Plateau, Morrison's, Victoria, Aus.

Fig. 2.—Conglomerate, containing rounded, sub-angular, and angular pebbles. The largest pebble is of limestone. Some of the pebbles are glaciated. From the Dwyka conglomerate (glacial), near Griquatown, South Africa. Five inches long.

PLATE 36.

Fig. 1.—Conglomerate with calcareous matrix and projecting jasper pebbles: Recent age. The calcareous material has weathered away. Beaconsfield, Griqualand, W., South Africa.

Fig. 2.—Pebble of Devonian conglomerate. Pebbles of quartz and red sandstone originally cemented together by sand. This sand has been altered by metasomatic action to white crystalline quartz. Glenfalloch, Macallister River, Victoria, Aus.

PLATE 37.

Fig. 1.—Pebble of Tertiary Grit. The grains are of quartz, and they are bound together with limonite. Black Rock, near Melbourne, Victoria, Aus.

Fig. 2.—Conglomerate Pebble, of Recent age. Jasper and other pebbles are bound together by calcareous material. Junction of Vaal and Orange Rivers, South Africa.

Fig. 3.—Pebble of Devonian conglomerate seamed with quartz veins. Glenfalloch, Macallister River, Gippsland, Victoria, Aus.

PLATE 38.

Fig. 1.—Pebble of fine conglomerate of Tertiary age. This conglomerate consists of small thoroughly rounded quartz pebbles cemented together with iron oxide. One mile north of Nowa Nowa, Victoria, Aus.

Fig. 2.—Pebble of still finer conglomerate of the same materials as Fig. 1, and from the same locality.

Fig. 3.—Sand conglomerate from same locality as Fig. 1.

PLATE 39.

Fig. 1.—Pebble of Schist. This pebble shows the connection between sedimentary beds and schists. Bedding planes are well marked. Granite Flat, Snowy Creek, Victoria, Aus. Four inches long.

Fig. 2.—Pebble of Schist, segregatory action commenced. Reefton, South Island, New Zealand. Five inches long.

PLATE 40.

Fig. 1.—Mica Schist Pebble. Crystalline structure of the felspars commencing. Reefton, South Island, New Zealand. Six and a half inches long.

Fig. 2.—Pebble showing a transition stage from schist to gneiss. Reefton, South Island, New Zealand. Six and a half inches long.

PLATE 41.

Fig. 1.—Pebble showing more gneissose character. Reefton, South Island, New Zealand. Six inches long.

Fig. 2.—Pebble of Gneiss. Reefton, S. Island, New Zealand. Six and a half inches long.

PLATE 42.

Fig. 1.—Pebble of Gneiss. Reefton, S. Island, New Zealand. Seven inches long.

Fig. 2.—Pebble of Granitic Gneiss. Reefton, S. Island, New Zealand. Six and a half inches long.

PLATE 43.

Fig. 1.—Pebble of Granitic Gneiss. Reefton, S. Island, New Zealand. Six inches long.

Fig. 2.—Pebble of Granitic Rock. The felspar assuming definite crystalline form. Reefton, S. Island, New Zealand. Five and a half inches long.

Fig. 1, Plate 39, shows that schists are formed from sedimentary beds. From Fig. 2, Plate 39, to Fig. 2, Plate 43, a series of stages is shown from schist, in which the atoms are metasomatically re-arranging themselves in the solid rock, until in Fig. 2, Plate 43, the outlines of the felspar crystals are well marked, and a granitic rock is in process of being formed. The embryo crystals are just beginning to separate in Fig. 2, Plate 39. The several minerals have nearly arranged themselves into granitic rock in Fig. 2, Plate 43.

PLATE 44.

Fig. 1.—Pebble of Schist, showing how the rudimentary crystals formed more freely along certain lines. These lines were formerly beds, but they have been much contorted. It is to be assumed that the material in such beds was in proportions suited to the formation of certain minerals—felspar in this case. Subsequently pebbles have been irregularly worn from this schist. Reefton, South Island, New Zealand.

Fig. 2.—Pebble of Gneiss, showing similar effect of segregatory action, but in a more advanced stage of alteration. Reefton, South Island, New Zealand.

Fig. 3.—Pebble of Schist, in which the metosamatic action is more developed along certain bedding planes than others. Highly contorted. Humphry's Gully, near Hokitiki, New Zealand.

PLATE 45.

Fig. 1.—Pebble of Schist, showing how the tortuous veins are probably beds of the original rock, that have become contorted. Reefton, South Island, New Zealand. Four inches long.

Fig. 2.—Pebble of Schist, with tortuous vein of felspar, which probably follows the original bedding plane, and which appears to have been formed by metasomatic action. The beds have been corrugated and crumpled. An-

other felspar vein cuts right across the tortuous one. From Reefton, South Island of New Zealand. Six inches long.

PLATE 46.

Fig. 1.—Pebble of Schist, showing a tortuous felspar vein. This vein was apparently originally a bed that has been highly contorted. The original material has been replaced by felspar. Reefton, South Island, N.Z. Six inches long.

Fig. 2.—Reverse of Fig. 1.

PLATE 47.

Fig. 1.—Pebble of Quartzite and Lydianite. Quartz veins have formed through the lydianite and quartzite by metasomatic action, that is without any filling of a fissure along the line of the vein, but by atomic replacement in situ. Marazion, Cornwall, England.

Fig. 2.—Pebble of Quartzite; dark grey in colour, showing distinct quartz veins. On one side (Fig. 2) these veins are sharply defined, but on the other side (Fig. 3) the quartz veins are indistinct, and are crossed by the bedding planes. It is clearly the case that these quartz veins result from metasomatic action—i.e., the particles of quartz have segregated into the veins in situ and from the adjacent material. The grains of silica already there were apparently altered, other silica added, and any impurities have been expelled along the course of the veins. Mitta Mitta township, Victoria, Aus Seven and a half inches long.

Fig. 3.—Reverse of Fig. 2.

PLATE 48.

Fig. 1.—Pebble of Schist, showing how quartz veins have formed in fissures in the rock.

Fig. 2.—Pebble of fine altered Sandstone with white quartz veins of several different ages intersecting it. Marazion, Cornwall, England.

Fig. 3.—Schist Pebble (altered Ordovician), showing dyke of euritic rock with a quartz vein on one side.

This illustrates the manner in which auriferous quartz veins occur alongside of dioritic dykes sometimes on one side, sometimes on the other, and occasionally on both sides, as at Warrandyte, etc., Victoria. The granite material was intruded in a heated condition. The quartz vein fills the shrinkage space caused by cooling. From Myrtleford, Victoria, Aus. Six inches long.

PLATE 49.

Fig. 1.—Pebble of Quartzite, with quartz vein through it. The vein is faulted, and although the displacement appears to be lateral, it is clear from the difference in thickness of the veins, and of the "horse" in the vein on either side of the fault, that the movement has been more probably at right angles to the apparent throw. Bairnsdale, Victoria, Aus. Four and one half inches long.

Fig. 2.—Pebble of Altered Sandstone showing a set of quartz veins faulted and intersected by a set of felspar veins. From "Oaklands," Claremont, near Cape Town, South Africa. Eight inches long.

PLATE 50.

Fig. 1.—Pebble of Sandstone, showing a system of quartz veins faulted and crossed by other quartz veins. The complicated nature of faults is exhibited. The movements are often extremely diversified, and in some cases the opposite sides of a fault oscillate in many directions before they reach their equilibrium. No rules can possibly be made to meet all the problems of such faults. Greymouth, South Island, New Zealand.

Fig. 2.—Reverse of Fig. 1.

PLATE 51.

Fig. 1.—Pebble of Sandstone (grey), with veins of black quartz, which have been intersected by white veins of two different ages. Hokitiki, South Island, New Zealand.

Fig. 2.—Pebble of Propylite, showing five successive ages of fracturing and filling with quartz veins. Humphry's Gully, Hokitiki, South Island, New Zealand. Six and a half inches long.

PLATE 52.

Fig. 1.—Pebble of Quartzite striated and polished by glacial action. From Derrinal, Victoria, Australia. Five inches long.

Fig. 2.—Pebble of siliceous material, covered by fine scratches produced by glacial action. Fraser's Creek Station, near Ashford Coal Mine, Northern New South Wales, Aus. Six inches long.

PLATE 53.

Fig. 1.—Pebble of fine grained Sandstone, showing striations caused by ice. Derrinal, Victoria, Aus.

Fig. 2.—Pebble of Sandstone, ground and scored by ice action. Wild Duck Creek, Derrinal, Victoria, Aus. Five inches long.

PLATE 54.

Fig. 1.—Glaciated Pebble of Mudstone: Scored. The Dwyka Conglomerate (glacial), Junction of the Orange and Vaal Rivers, South Africa.

Fig. 2.—Glaciated Pebble, of igneous rock showing deep scoring on the obverse side. Dwyka conglomerate. Prince Albert, Cape Colony. Four inches long.

Fig. 3.—Glaciated Pebble reverse side of Fig. 2, showing the fractures that have resulted on the side opposite to that on which the pressure was exerted.

PLATE 55.

Fig. 1.—Pebble of Claystone, facetted by ice action. From the Dwyka conglomerate; Twee Fontein, Diep River, near Hope Town, Cape Colony, South Africa. Four inches long.

Fig. 2.—Pebble of Sandstone facetted by ice action. Derrinal, Victoria, Aus. Five inches long.

PLATE 56.

Fig. 1.—Glaciated Pebble, showing characteristic form. Wild Duck Creek, Heathcote, Victoria, Aus.

Fig. 2.—Angular Pebble (glacial). This pebble has been nipped by the ice in a glacier, and flakes have been detached. The Dwyka Conglomerate, 2 miles North of the junction of the Orange and Vaal Rivers, South Africa.

Fig. 3.—Nipped stone, showing natural flaking caused by glacial action. Taken out of a glacier by the writer. Gorner Grat, Switzerland. Compare with Fig. 2. Plate 56.

PLATE 57.

Fig. 1.—Australite or Obsidianite. Button shaped, upper side. Mt. William, Grampians, Victoria, Aus.

Fig. 1a.—Same as Fig. 1, underside.

PLATE 58.

Fig. 2.—Australite; button shape; side view. Mt. William, Grampians, Victoria, Aus.

Fig. 3.—Australite; centre of a button form from which the rim has been removed. It has been water-worn into a pebble. Craigie, New South Wales, near east boundary of Victoria. Found by Mr. S. B. Hunter, Brighton, Victoria.

Fig. 4.—Australite. A double bubble, divided by a thin diaphragm. The interior walls highly polished. Probably the bleb from such a double bubble; if it had been further inflated, would be of a dumbell form. This was the centre of a button form from which the rim has been removed, and which has been somewhat sand worn. Charlotte Waters, South Australia. Presented by Mr. H. Y. L. Brown, Government Geologist, of South Australia.

Fig. 5.—Australite; side view of Fig. 3, Plate 57.

Fig. 6.—Australite; upper side of Fig. 7, Plate 57.

Fig. 7.—Australite; upper side of centre of button form from which the rim has been removed. Mt. William, Grampians, Victoria, Aus.

Fig. 8.—Australite; centre of button form. Coolgardie, West Australia. Presented by Mr. Ward, Assistant Government Geologist, Tasmania.

Fig. 9.—Australite; same as Fig. 7, but view of under side.

Fig. 10.—Australite; same as Fig. 6, view of under side. Presented by Mr. Campbell, Assistant Geologist, Perth, W. Australia.

Fig. 11.—Australite; centre of long form; side view. Dry Lakes, Coolgardie.

Fig. 12.—Australite; same as Fig. 8, Plate 57; upper side.

Fig. 13.—Australite; same as Fig. 8, Plate 57; under side.

Fig. 14.—Australite; same as Fig. 11; upper side.

Fig. 15.—Australite; centre of button form, 2 inches in diameter, from which the rim has been removed (outside). This is a hollow sphere or bubble. The upper side is as placed in the plate. Hamilton, Victoria, Aus. Kindly lent by Professor Spencer, C.M.G., from the National Museum, Melbourne.

Fig. 16.—Same as Fig. 15, showing inside of bubble. The wall at the top is thinner than the rest, as the imprisoned gas pressed most in that direction. The inner surface is highly polished.

PLATE 59.

PLATE 60.

PLATE 61.

PLATE 62.

PLATE 63.

FIG. 1.—Well water-worn flat pebble of Schist with lichen growing on it. Granite Flat, Victoria, Aus. Four inches long.

FIG. 2.—Pebble of Sandstone, covered with lichen. "Klip Bloem," of the South Africans. Stormberg, Cape Colony, South Africa.

PLATE 64.

FIG. 1.—Limpet-covered Pebble. Waiwera, North Island, New Zealand.

FIG. 2.—Pebble covered with Vermilia Crespitosa. From the beach, Cunningham, Victoria, Aus.

FIG. 3.—Oyster shell on Pebble. The pebble is of fine sandstone. Gough's Harbour, New South Wales, Aus.

FIG. 4.—Pebble covered with Lithophyllum, Serpula, Polyzoa and Spirorbis. From the sea beach, Cape Schank, Victoria, Aus. Kindly determined by Mr. F. Chapman, Palaeontologist, National Museum, Melbourne.

PLATE 65.

FIG. 1.—Sandstone Pebble ("Box Stone"), enclosing left valve of Glycimeris glycimeris. From the Crag conglomerate. Suffolk, England. Kindly lent by Mr. Rivers Langton, of Kew, Victoria, Aus.

FIG. 2.—Shows a fragment detached from the "Box Stone," with the cast of the inside of the shell.

FIG. 3.—Cast of left valve of the shell of Glycimeris. The valve began to decay, and grains of sand accreted around it; this action went on until a concretion was formed around the whole of the valve. The shell itself became completely embedded in the sand, and as it decayed, the lime served to bind the sand particles together. Eventually the whole of the lime in the shell was dissolved out and a hollow mould was left, the one side (Fig. 2) showing the cast of the inside of the valve, and the other (Fig. 3) showing the cast of the outside of the valve. After the concretion was fully formed it was worn down into a pebble by water action. Later it became embedded in a conglomerate consisting of box stones, coprolite, bones of whales, etc., and it was by human agency broken out of the matrix, which was highly ferruginous. The Crag, Suffolk, England.

PLATE 66.

FIG. 1.—Pebble formed from a flaked stone implement. Originally this was a Bushman implement chipped from a piece of lydianite. The implement when discarded was exposed at the surface sufficiently long for a grey patina to form on this intensely hard material. Later it was swept into the Modder River and partly water-worn, the patina being removed on the ridges. Modder River, Orange River Colony, South Africa.

FIG. 2.—Same as Fig. 1 and from same locality. These are Pebbles of natural material, artificially shaped, and subsequently water-worn by natural means.

FIG. 3.—Pebble of Brick. Rounded by wave action. Natural material, artificially moulded, burnt and transported. Rounded by natural means. Marazion, Cornwall, England.

FIG. 4.—Pebble of Glass—part of the bottom of a black bottle rounded by the waves. Artificial material and transport. Worn into a pebble by natural means. Russell, North Island of New Zealand.

FIG. 5.—Pebble of Glass; bottom of a tumbler. Well rounded by wave action. Marazion Beach, Cornwall, England.

FIG. 6.—Pebble of Granite. Formed from waste material of a granite quarry that was tipped into the sea—natural material artificially broken from the parent mass and transported to the sea, then naturally rounded by wave action. Rough spalls are thus rapidly converted into well-rounded pebbles. Jersey, Channel Islands.

PLATE 67.

FIG. 1.—Quartzite Pebble smeared with red ochre. This stone is used by the blacks of Central Australia, who call it "Churinga Unchima." It is supposed to represent the egg, which produces a grub, that gives its name to a totem in the Arunta tribe. These stones are carefully kept in sacred stone-houses, and are only handled by the men of the grub totem when they are performing ceremonies, for the purpose of ensuring an abundant supply of the grubs. Kindly lent by Professor Spencer, C.M.G., from the National Museum.

Fig. 2.—Perforated Stone of Basalt. This is a Ghost Stone, and is used by the Medicine Man on the occasion of the great festivals of the year, when there is a large gathering and much excitement. In the midst of the excitement this stone, which has a thong attached to it, is hurled by the Medicine Man into the midst of the throng, and the one it strikes is immediately seized, sacrificed and cooked, and provides a feast for the revellers. New Hebrides, Pacific Islands.

PLATE 68.

Fig. 1.—Pebble sinker, fastened on a piece of light wood; used in fishing. The tortoise-shell hook is baited and thrown out; then the piece of wood is cast into the lagoon and floats in an upright position, and if a fish bites, the stick indicates this by its movements. New Hebrides, Pacific Islands. The float is three feet long.

Fig. 2.—Sling Stones. "Pebbles from the brook" in the Bible account of David's exploit with Goliath. Used in a sling. Most of the sling stones are made of serpentine rubbed into the form of cylinders with sharp ends, but these were obtained by the writer among such shaped stones from a native. New Caledonia.

Fig. 3.—Pebble used in fishing as sinkers on floats of light wood. New Hebrides. The float is one foot long.

Fig. 4.—Pebble used as Sling Stone. New Caledonia.

Fig. 5.—Pebble of Rock Crystal. Used as a sacred object by the Blacks. Gippsland, Victoria, Aus.

PLATE 69.

Fig. 1.—Pebble, chipped on one side of an end, so as to form a rough hand hatchet. Perhaps the most primitive form of an axe, and from such a beginning even the latest American axe has been eventually evolved. Mitta Mitta River, six miles above the junction of Dark River. Six inches long.

Fig. 2.—Pebble Tomahawk. Formed by chipping a pebble on one side of one end, and by then grinding a cutting edge on that end. Used by the blacks Dederang, N.E. Victoria, Aus. Six inches long.

PLATE 70.

Fig. 1.—Muller made from Pebble. Used for grinding colours, etc., by Hottentots. Port Nolloth, South Africa.

Fig. 2.—Muller made from Pebble. Transvaal, South Africa.

Fig. 3.—Muller made from Pebble. Used by Hottentots (Strand-loopers) for grinding their corn, etc. Cape Flats, near Cape Town, South Africa.

PLATE 71.

Fig. 1.—Pebble formed into Muller. Kaffir, E. Transvaal.

Fig. 2.—Mealing Stone. Made from a pebble. Used by the Blacks for grinding grass seeds on Netley Station, Darling River, New South Wales, Aus.

PLATE 72.

Fig. 1.—Hammer made from a cylindrical Pebble, used for flaking stones by Bushmen. Stormberg, Cape Colony, South Africa.

Fig. 2.—Muller made from Pebble. Used by Kaffirs for grinding seeds, etc. Nel's River, near Pilgrim's Rest, Transvaal, South Africa.

Fig. 3.—Perforated Pebble. Used by Bushman women as a weight for their digging sticks, by means of which they procure roots for food. Stormberg, South Africa.

PLATE 73.

Fig. 1.—Arrow straightener made from a Pebble. Used by Bushmen for straightening the reed shafts of their arrows. This is done by heating the stone in a fire and then passing the thin reed through the groove until the shaft is quite straight. Leeuw Fontein, Stormberg, South Africa.

Fig. 2.—Pebble of Greenstone (Jade) made into an ear pendant by Maoris. The pebble is roughly ground and perforated. North Island, New Zealand.

Fig. 3.—Sinker made from a Pebble. A groove is picked around it, and it was used for weighting fishing nets and lines. West coast of Great Barrier Island, New Zealand.

PLATE 74.

Fig. 1.—Sinker made from a Pebble. For fishing nets and lines. Port Fitzroy, Great Barrier Island, New Zealand.

Fig. 2.—Sinker made from a Pebble. Used by Maoris for fishing nets, etc. North Island, New Zealand.

PLATE 75.

Fig. 1.—Greenstone Pebble (Jade or Pounumu of the Maoris). From river near Humphry's Gully, Hokitiki, South Island, New Zealand. Ten inches long.

Fig. 2.—Greenstone (Jade) Pebble. Split and partly rubbed down so as to form a Hei Tiki or an adze. North Island, New Zealand. Eight inches long.

PLATE 76.

Fig. 1.—Portion of a Greenstone (Jade) pebble in process of being fashioned into a Hei Tiki. North Island, New Zealand.

Fig. 2.—Hei Tiki of Greenstone in more complete form. South Island, New Zealand.

Fig. 3.—Hei Tiki made from a Greenstone Pebble. Highly finished example. North Island, New Zealand.

These Hei Tikis were greatly prized by the Maoris. Similar carved stones were widely used in Mexico, where grotesque faces were carved on pebbles (examples in the British Museum). The Maoris can be traced back to the north-west coast of North America, where their kinsmen still live at Nootka Sound and the Queen Caroline Islands. In this way, the Mexican carved pebbles and the Maori Hei Tiki may be the work of the same people. In Egypt similar grotesque faces were carved on stone. In Carthage the Phœnicians used something similar, and the Greek "Stone with a Soul" was probably of a similar nature. If, as seems probable, the Egyptians had colonies in America, the art of carving such stones may have been taught the natives by the Egyptians. It is quite possible that faces carved on pebbles such as those found in Mexico may represent the very beginning of the art of sculpture, and from such beginnings the art of sculpturing heads and busts may have been slowly evolved.

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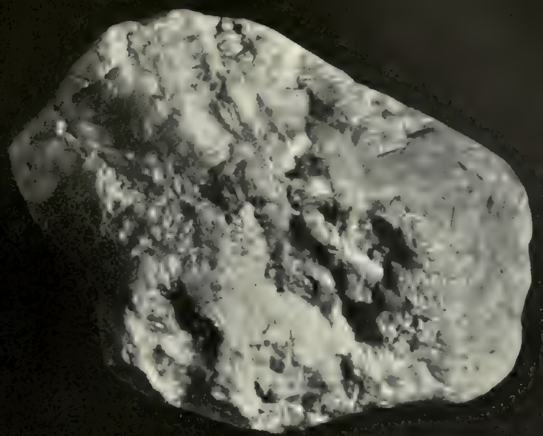
PLATE I



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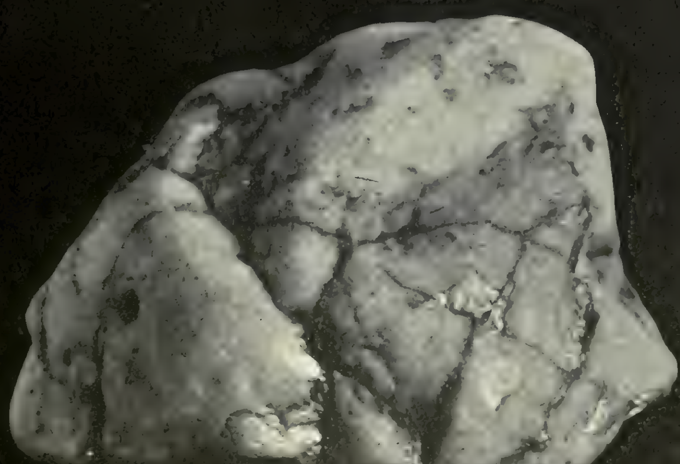

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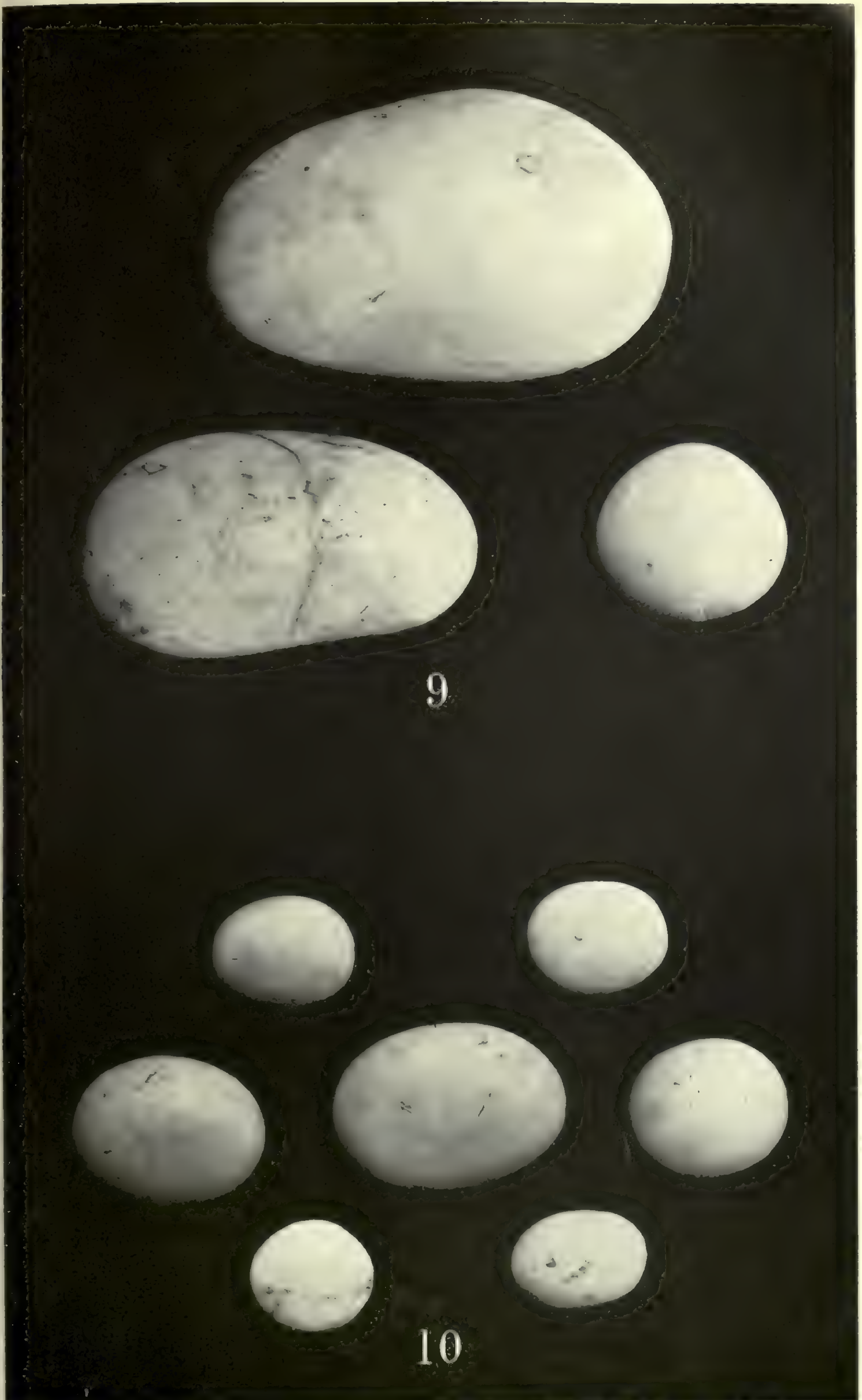
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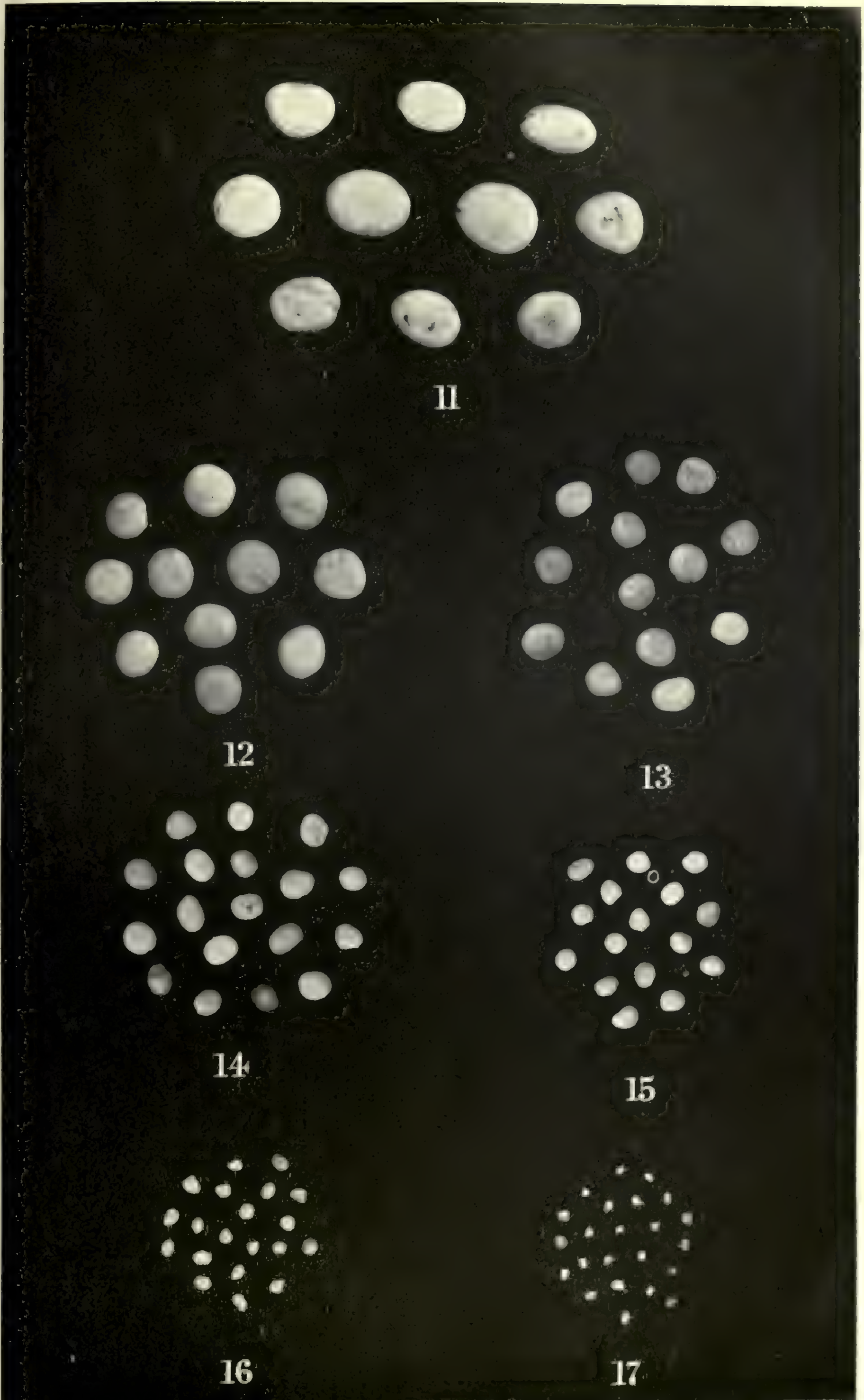
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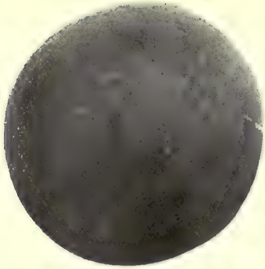

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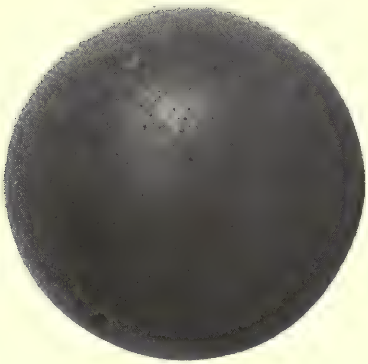

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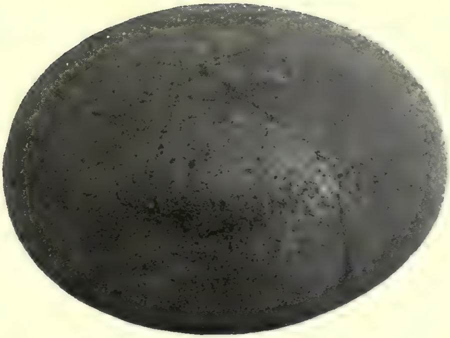

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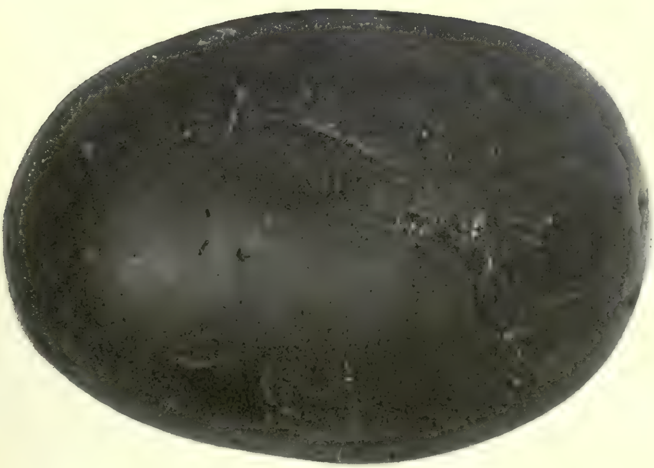

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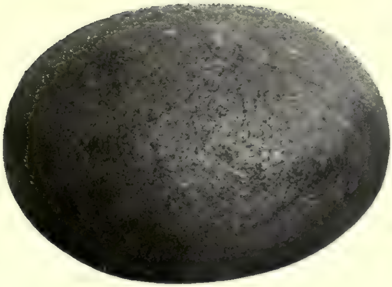

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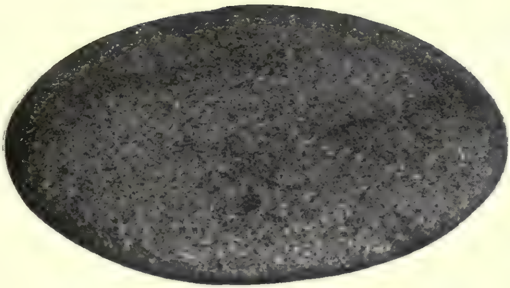

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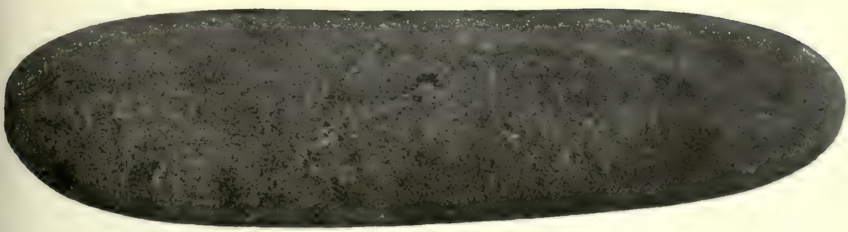

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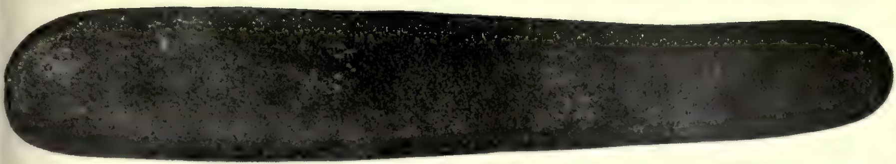

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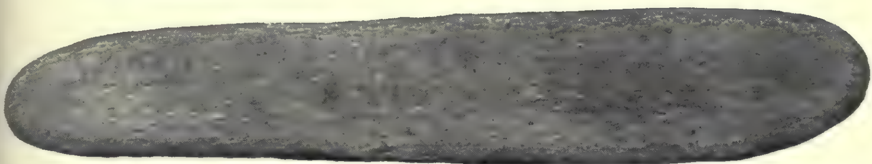

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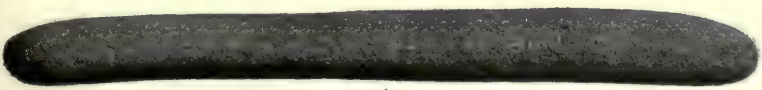

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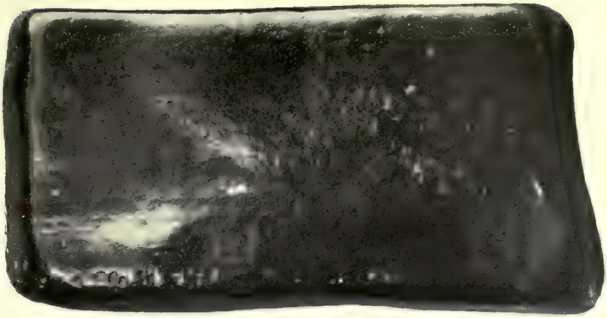

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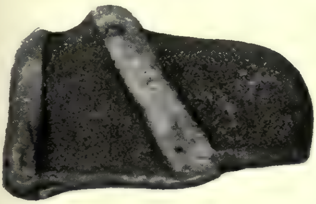

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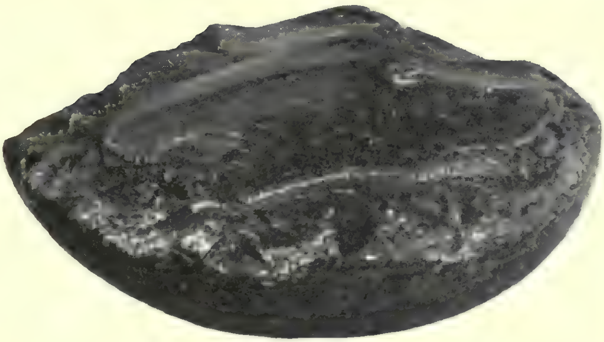

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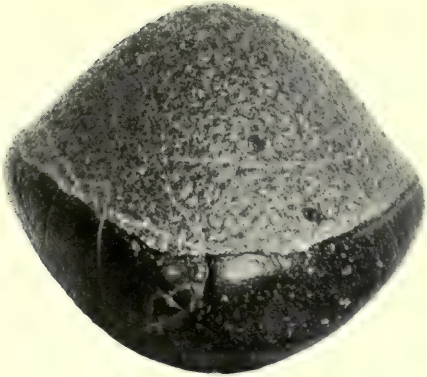

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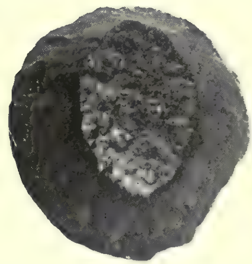

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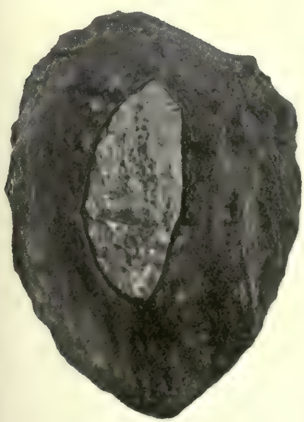

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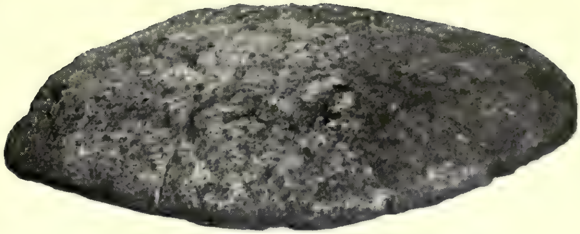

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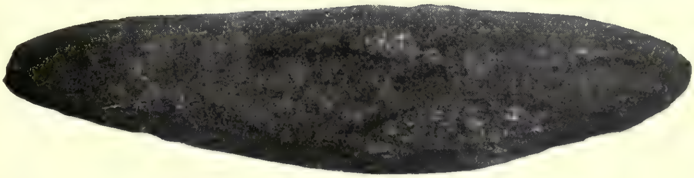

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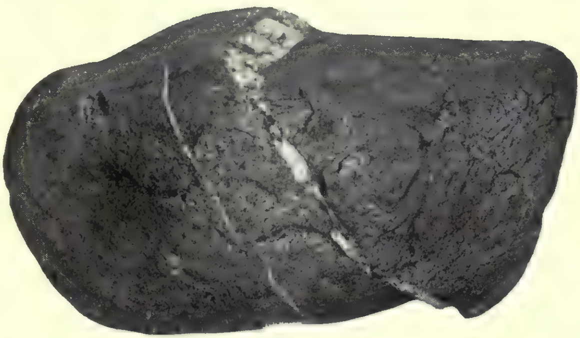

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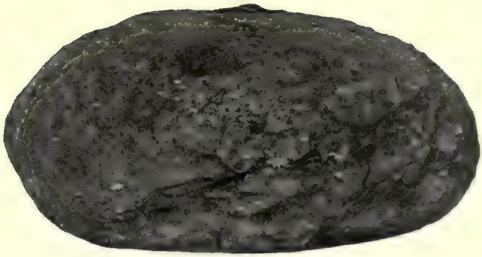

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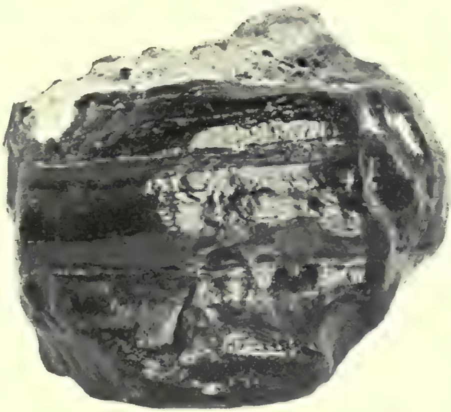

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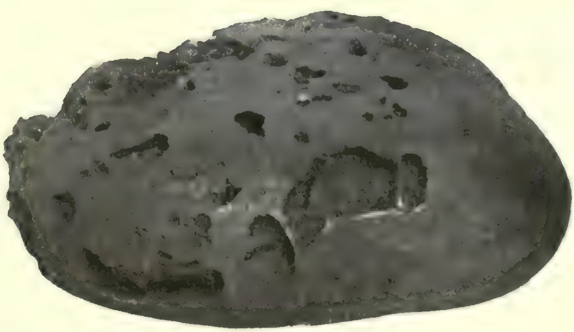

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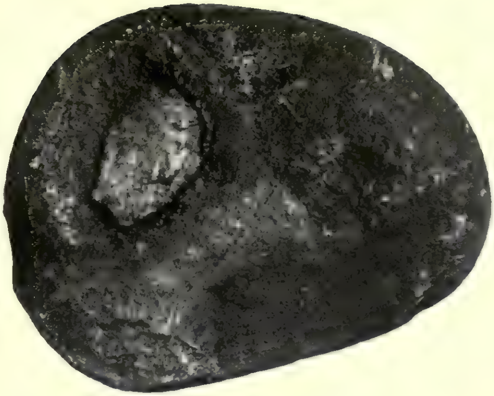

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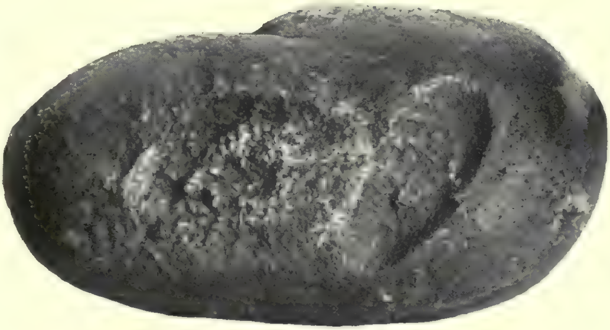

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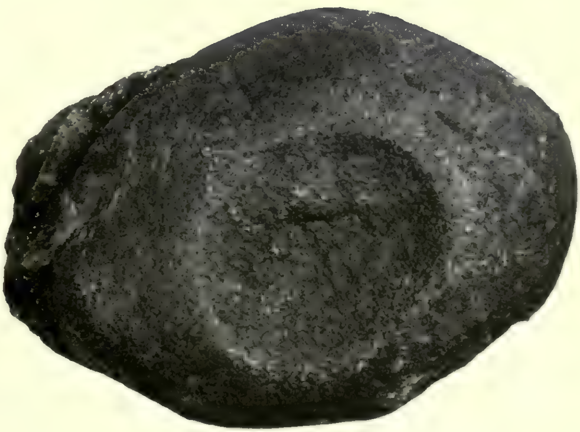

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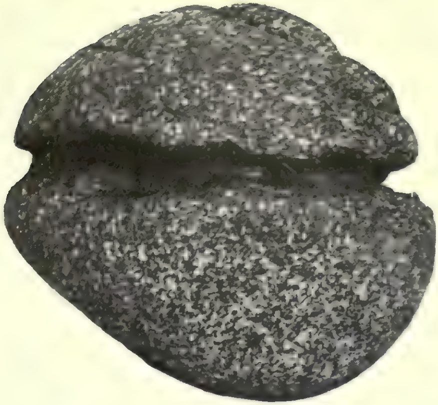

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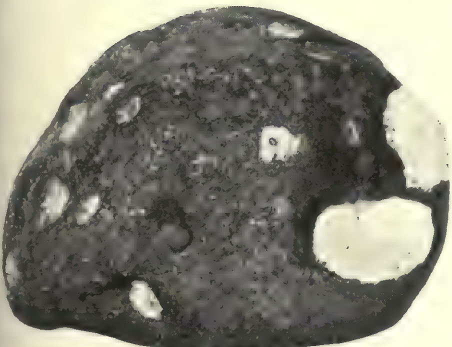

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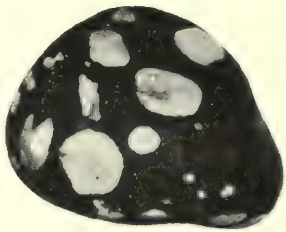

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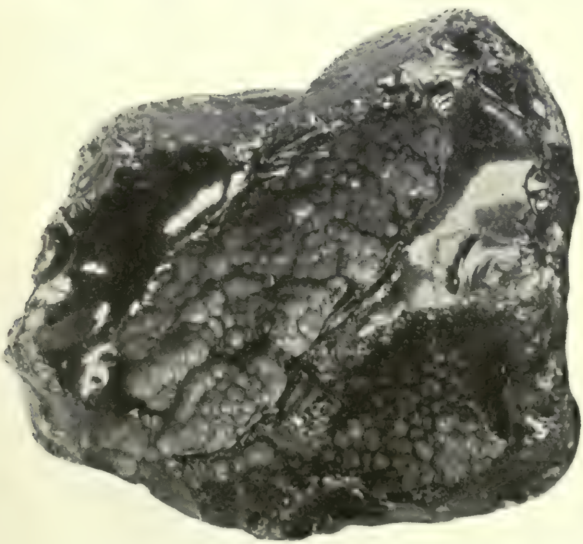

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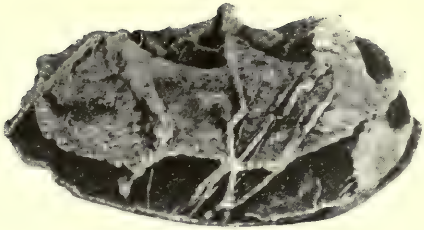

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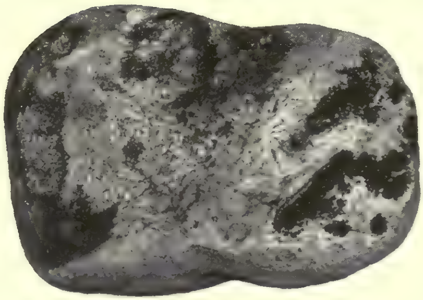

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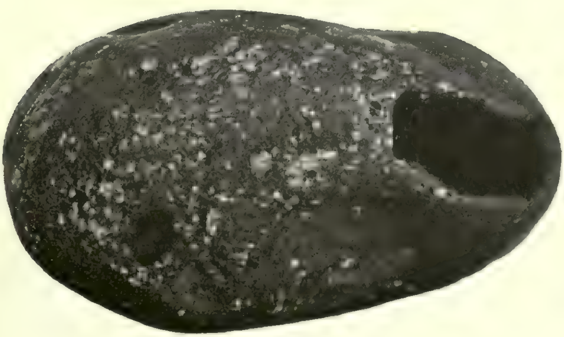

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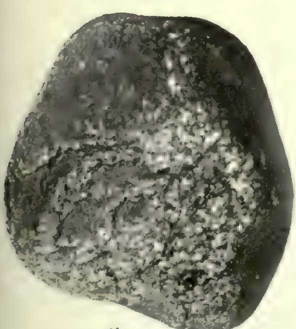

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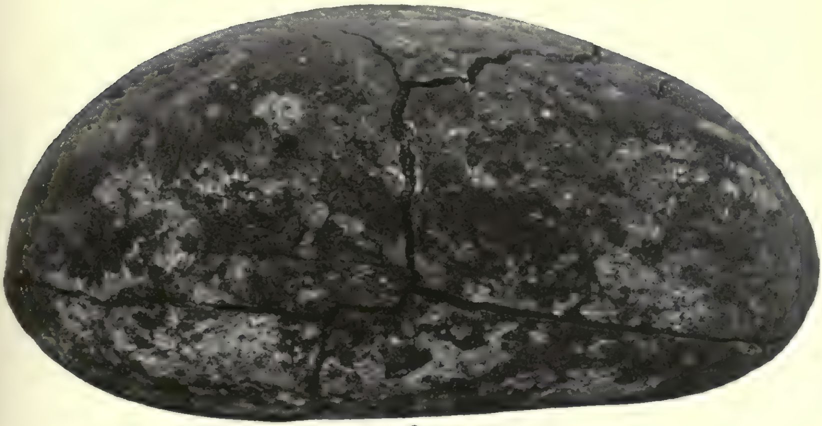

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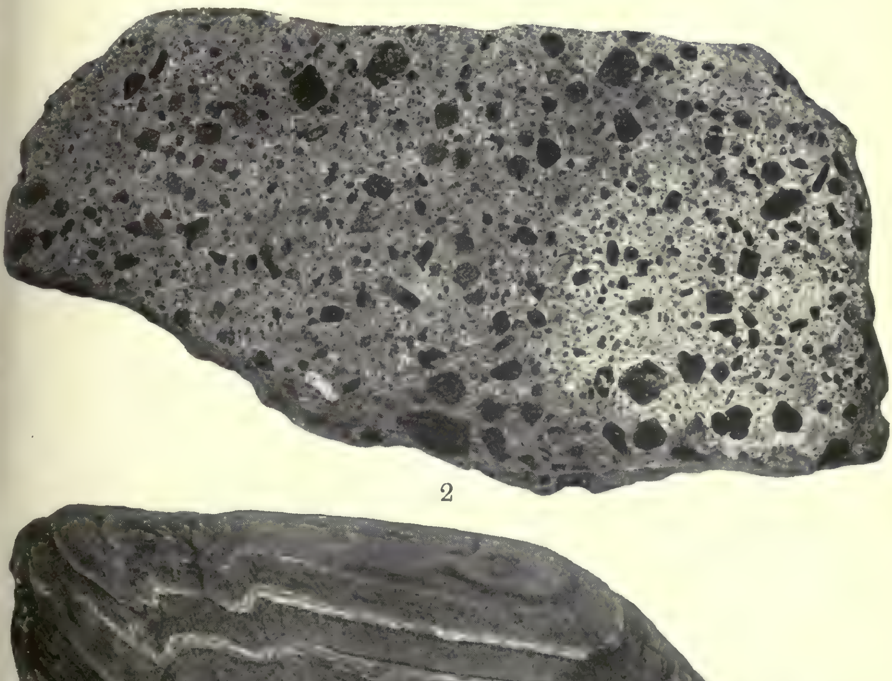

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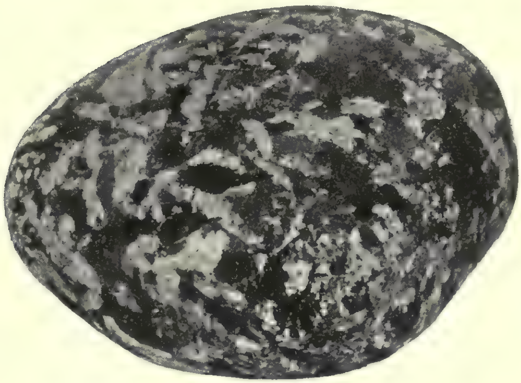

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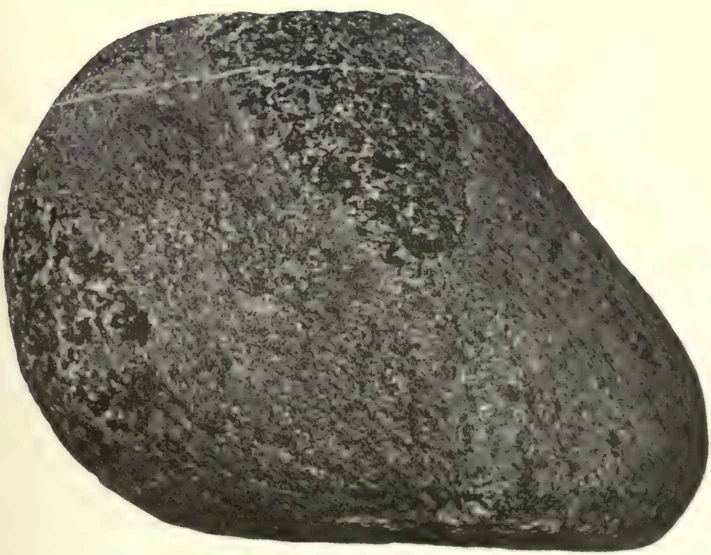

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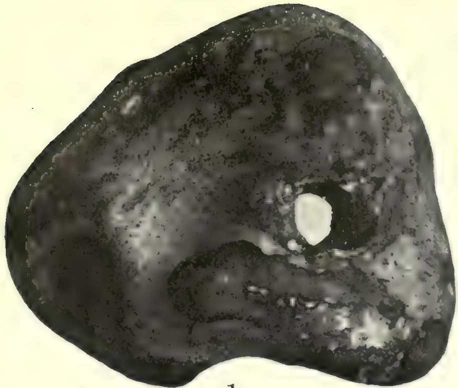

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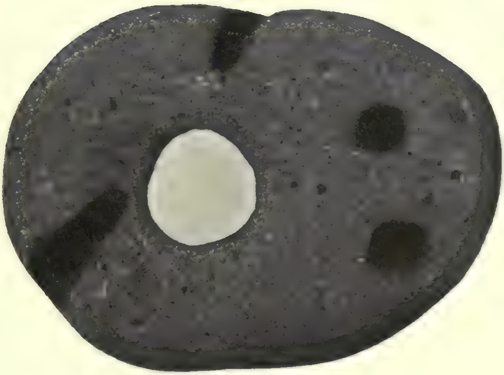

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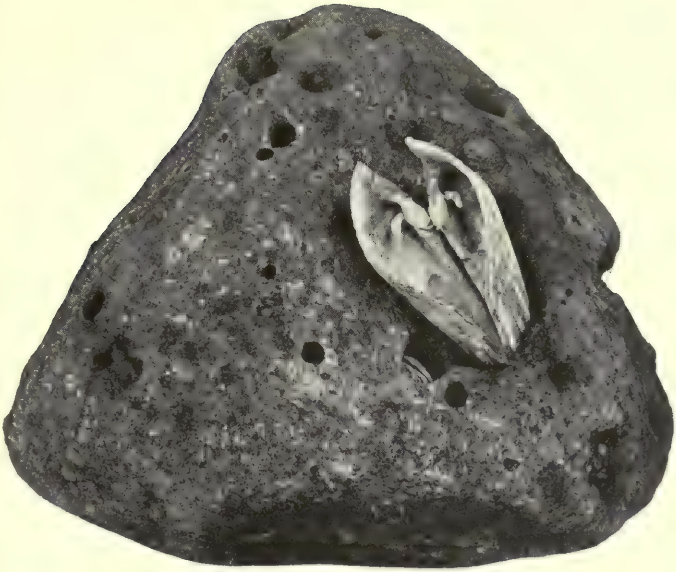

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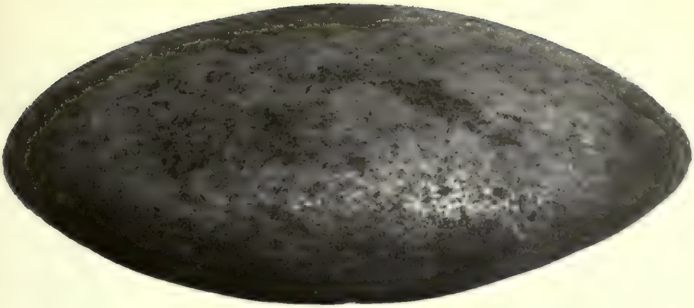

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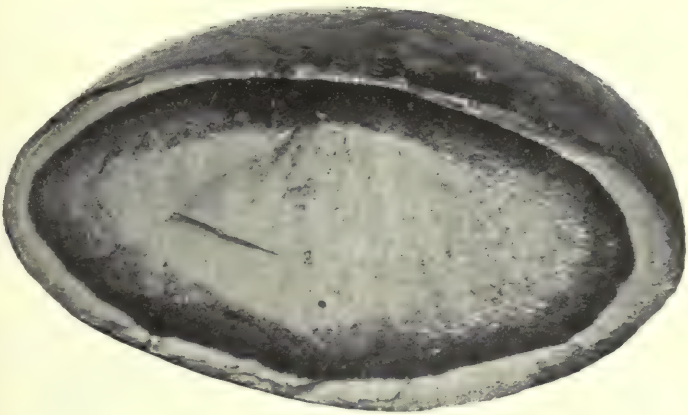

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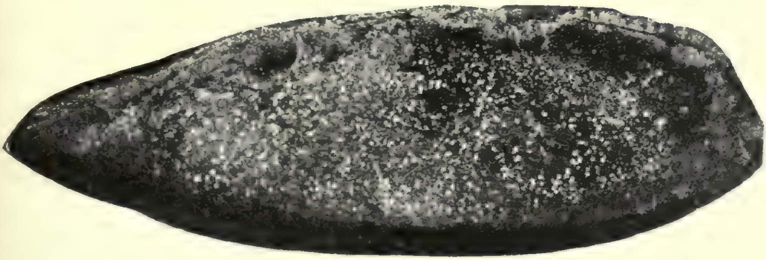

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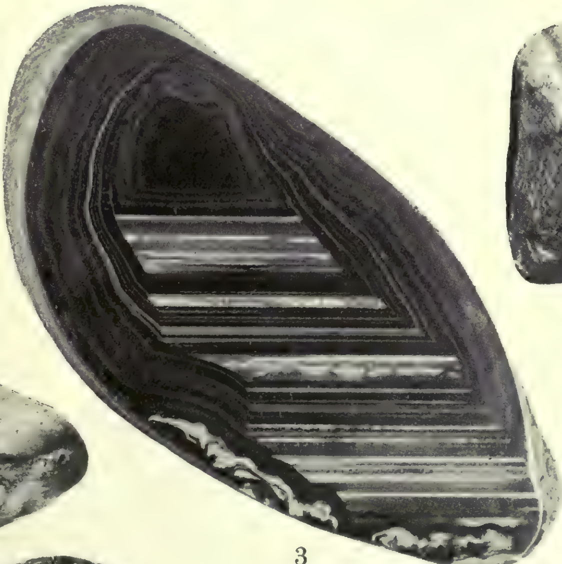

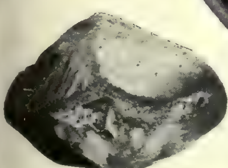

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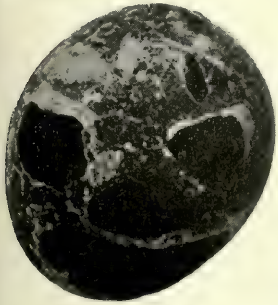

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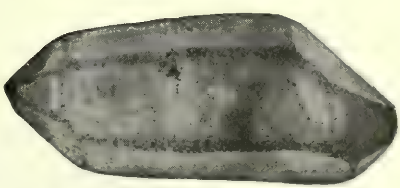

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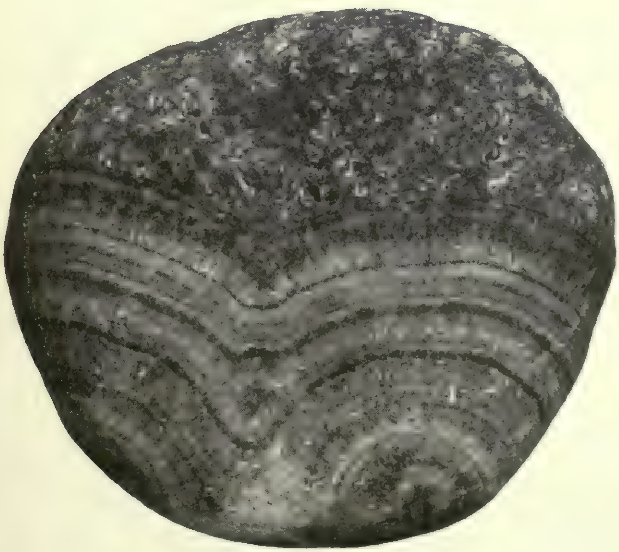

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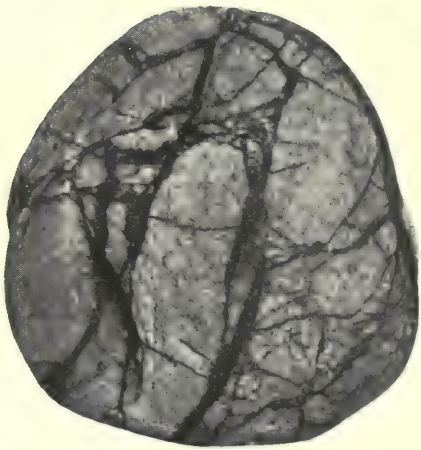

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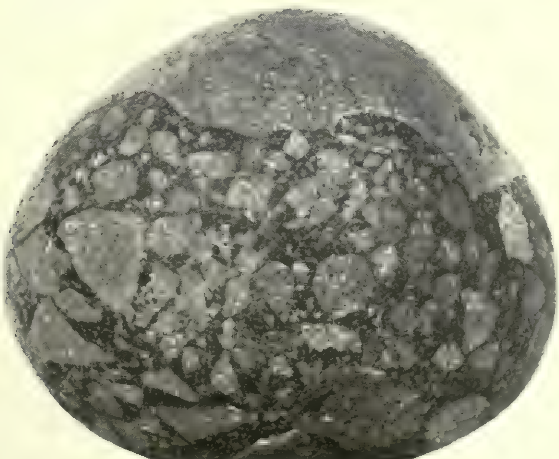

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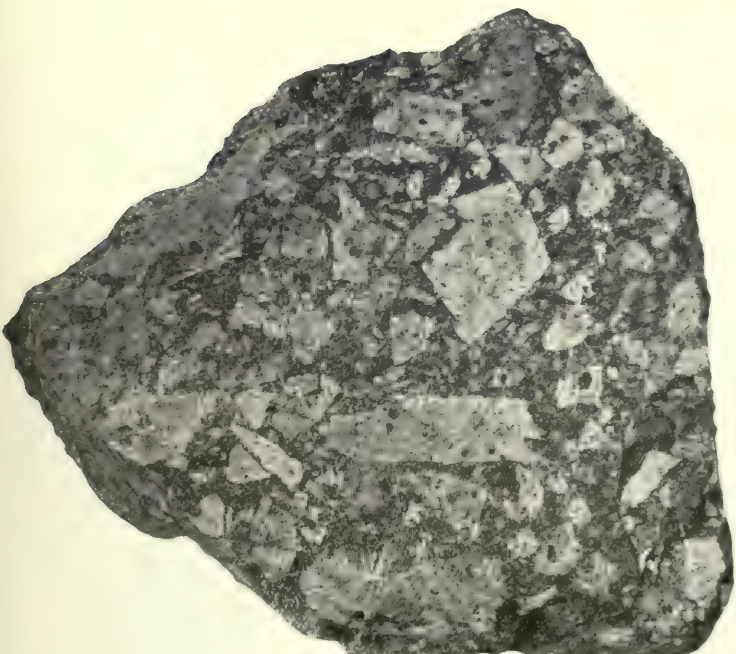

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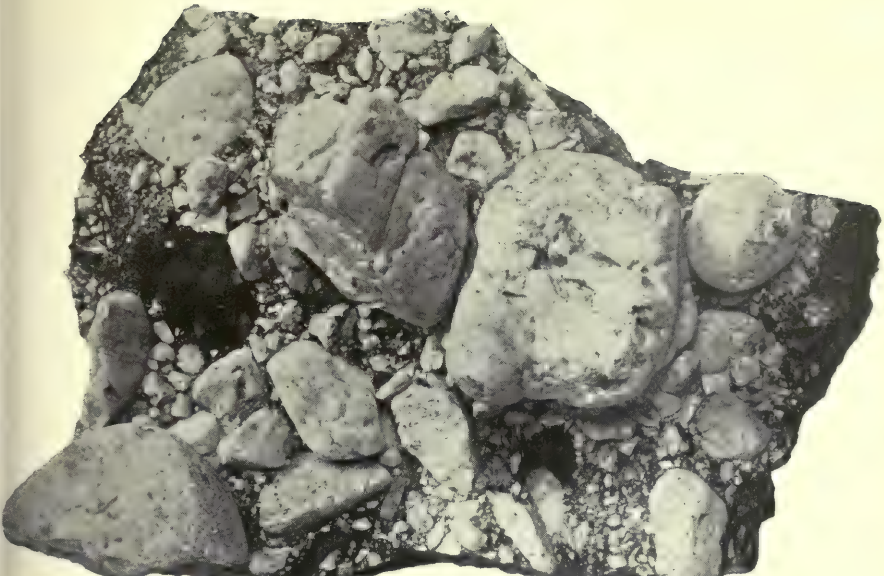

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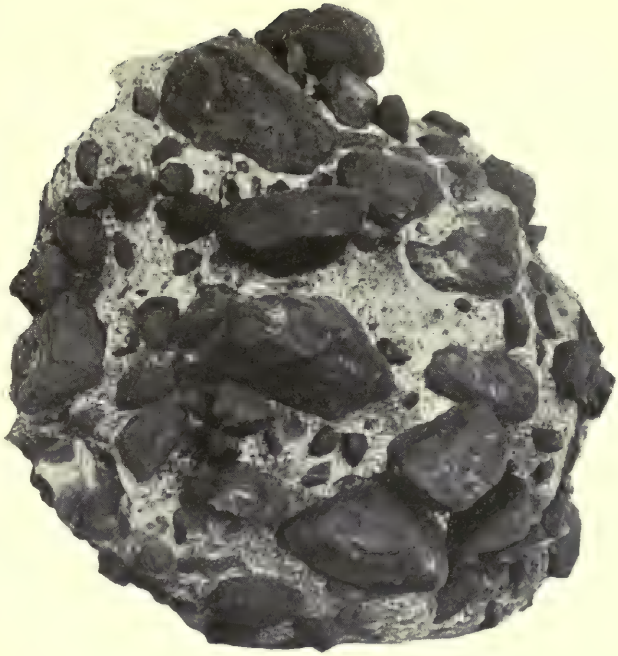

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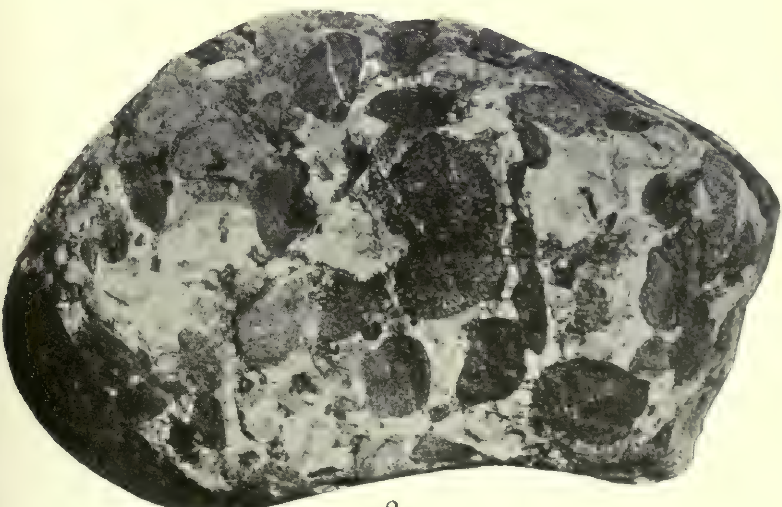

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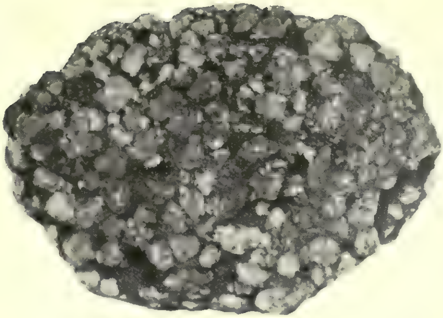

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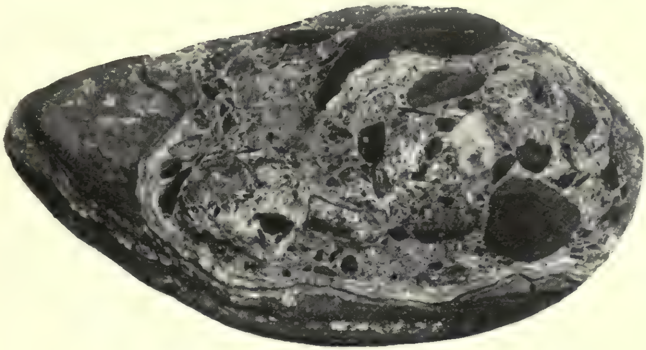

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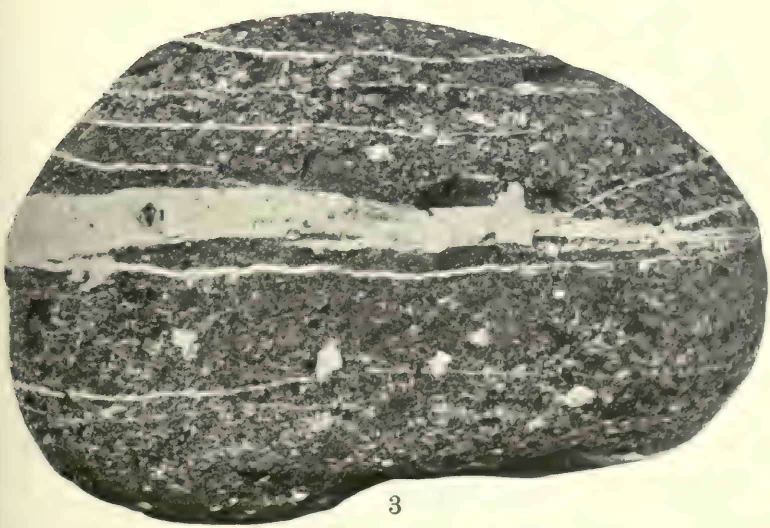

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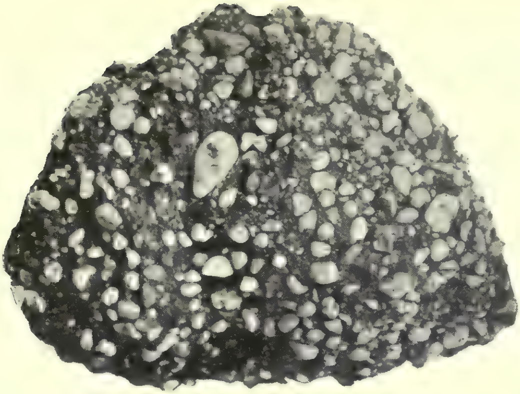

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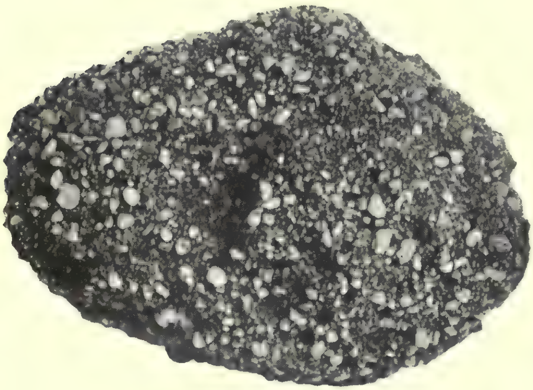

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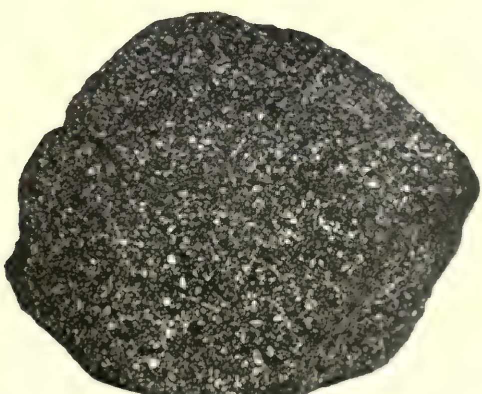

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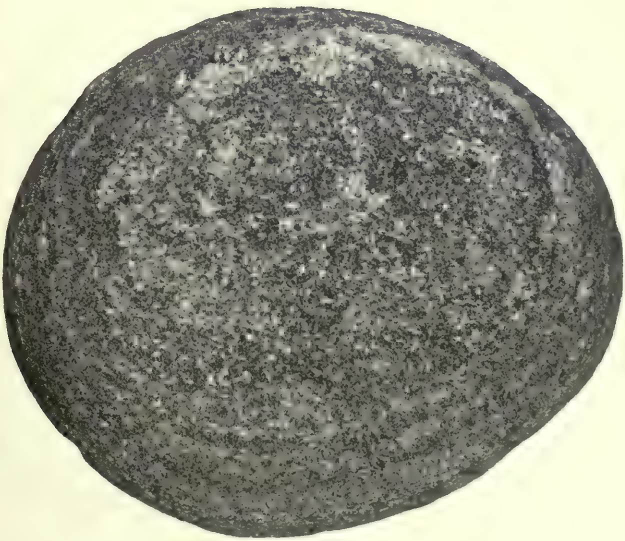

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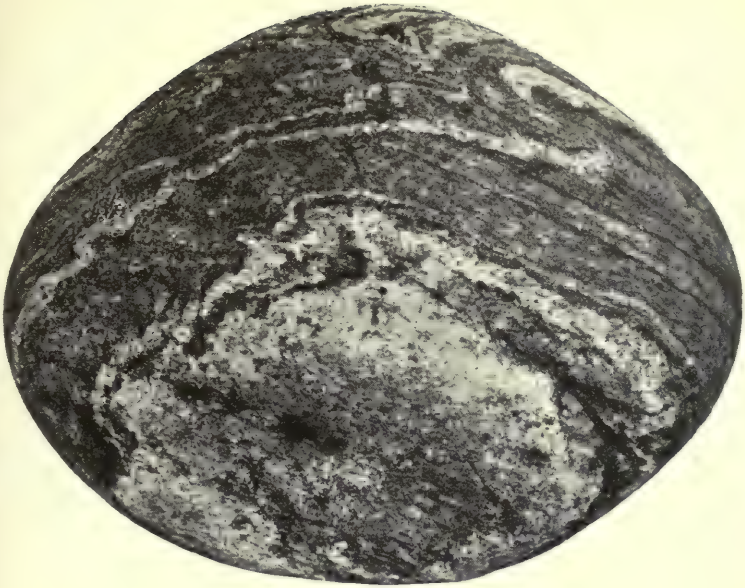

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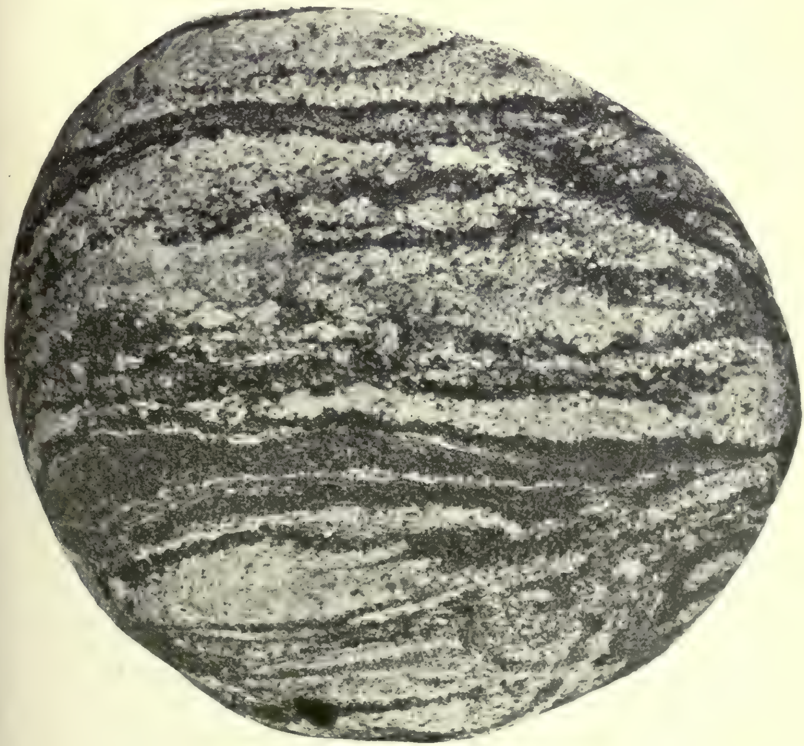

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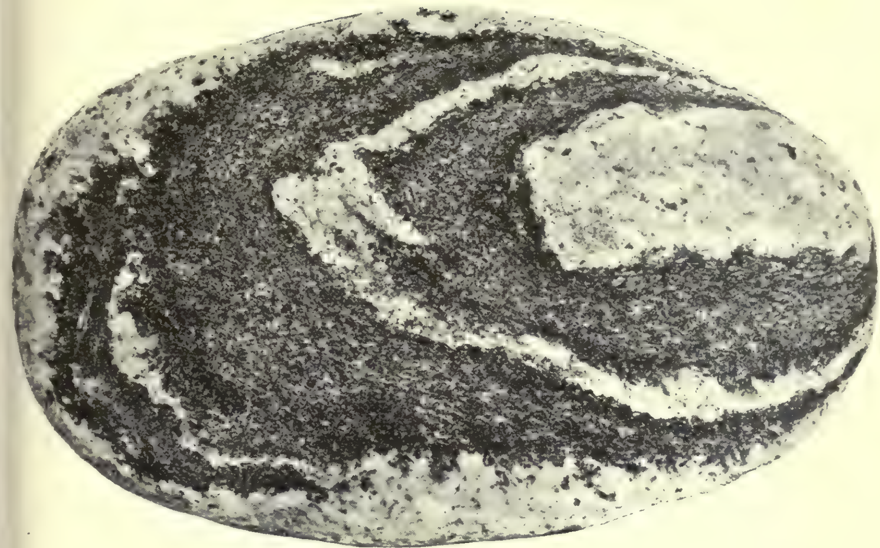

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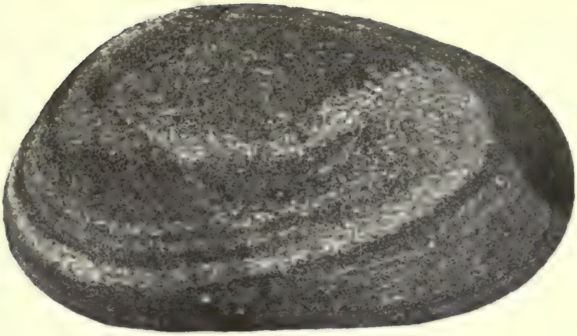

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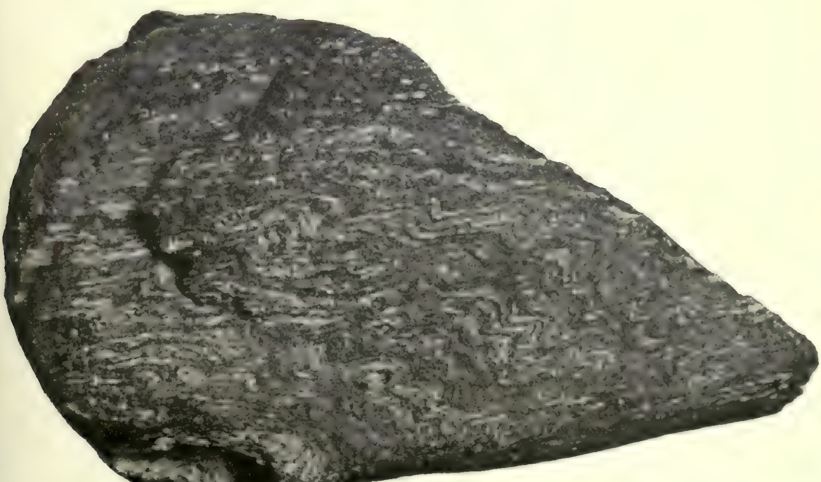

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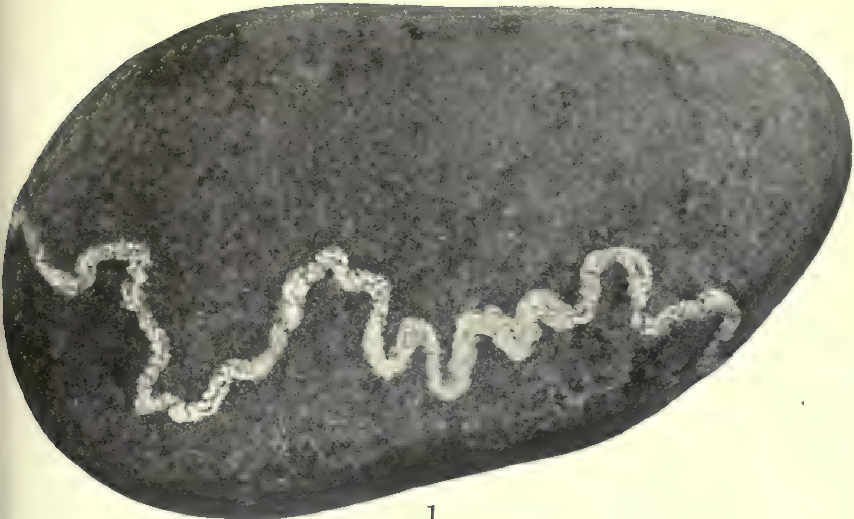

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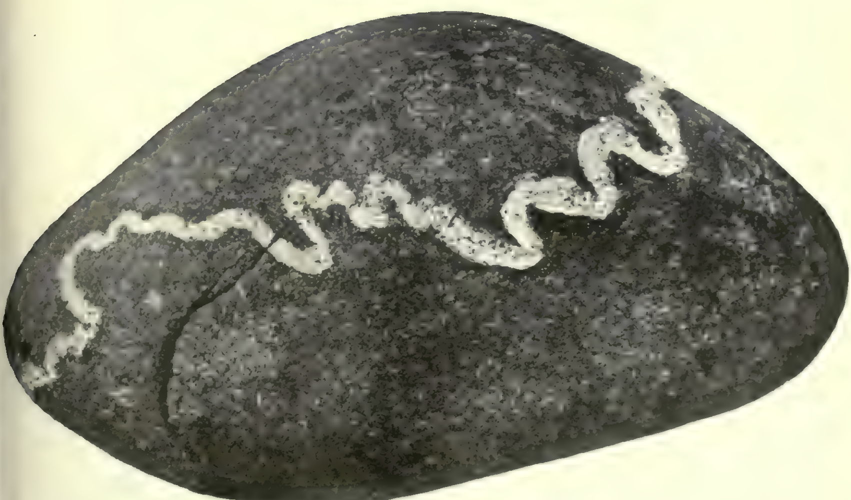

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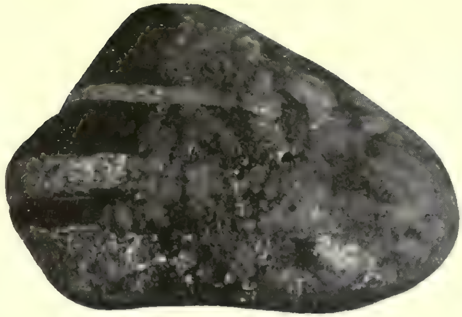
PLATE 47



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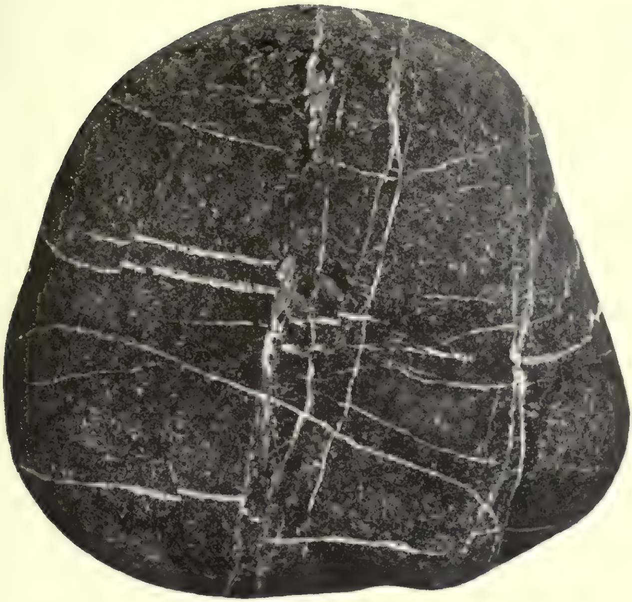

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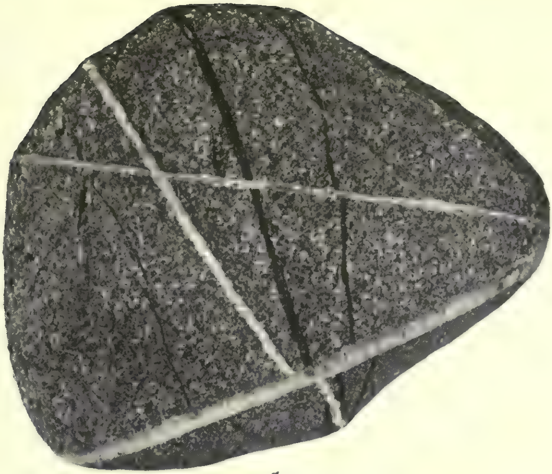

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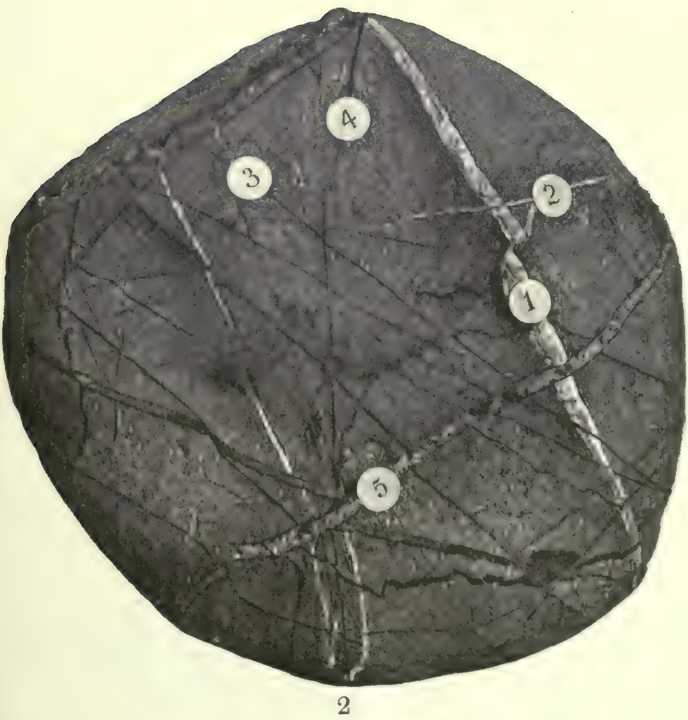

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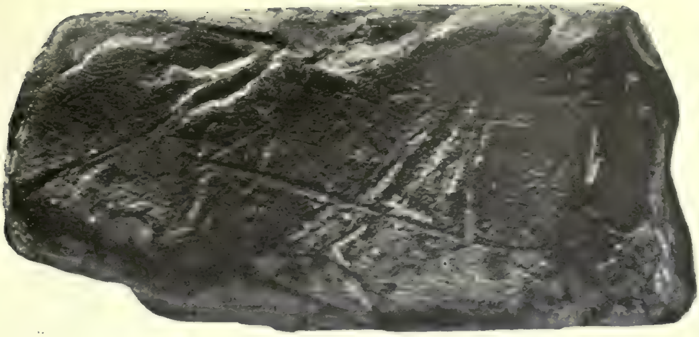

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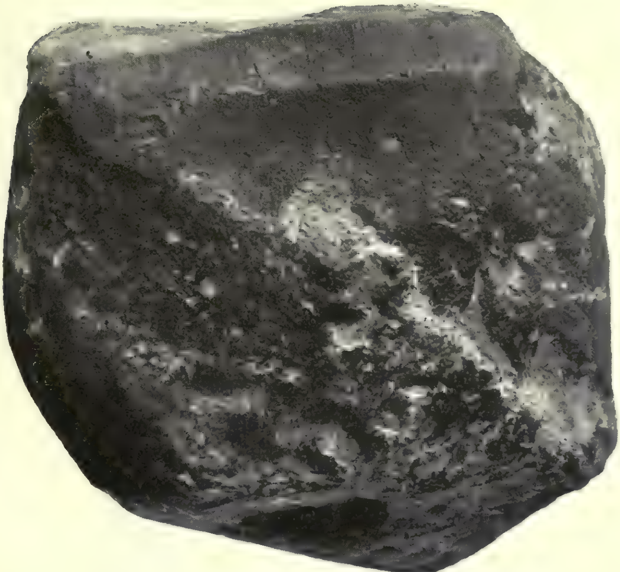

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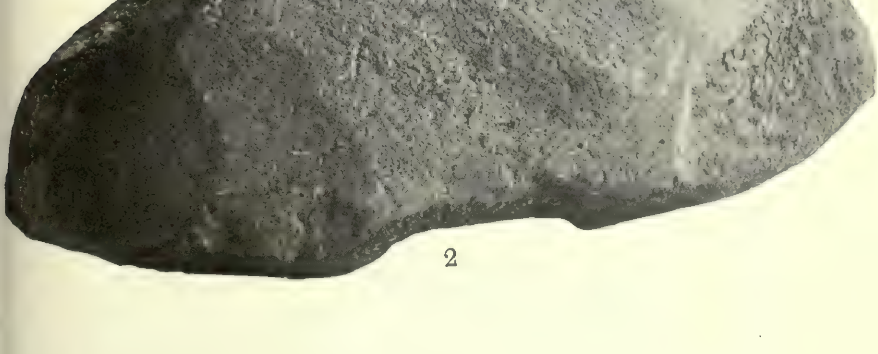

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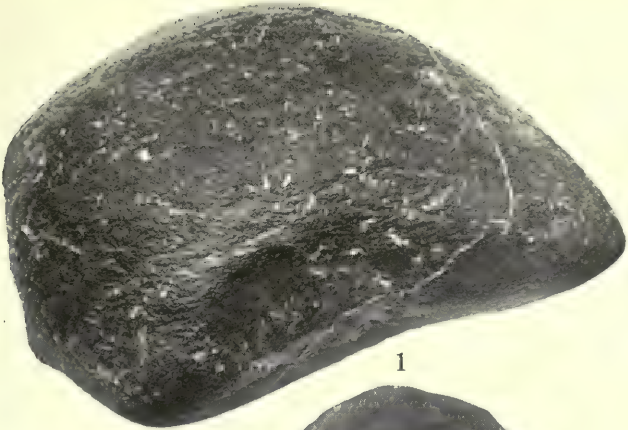

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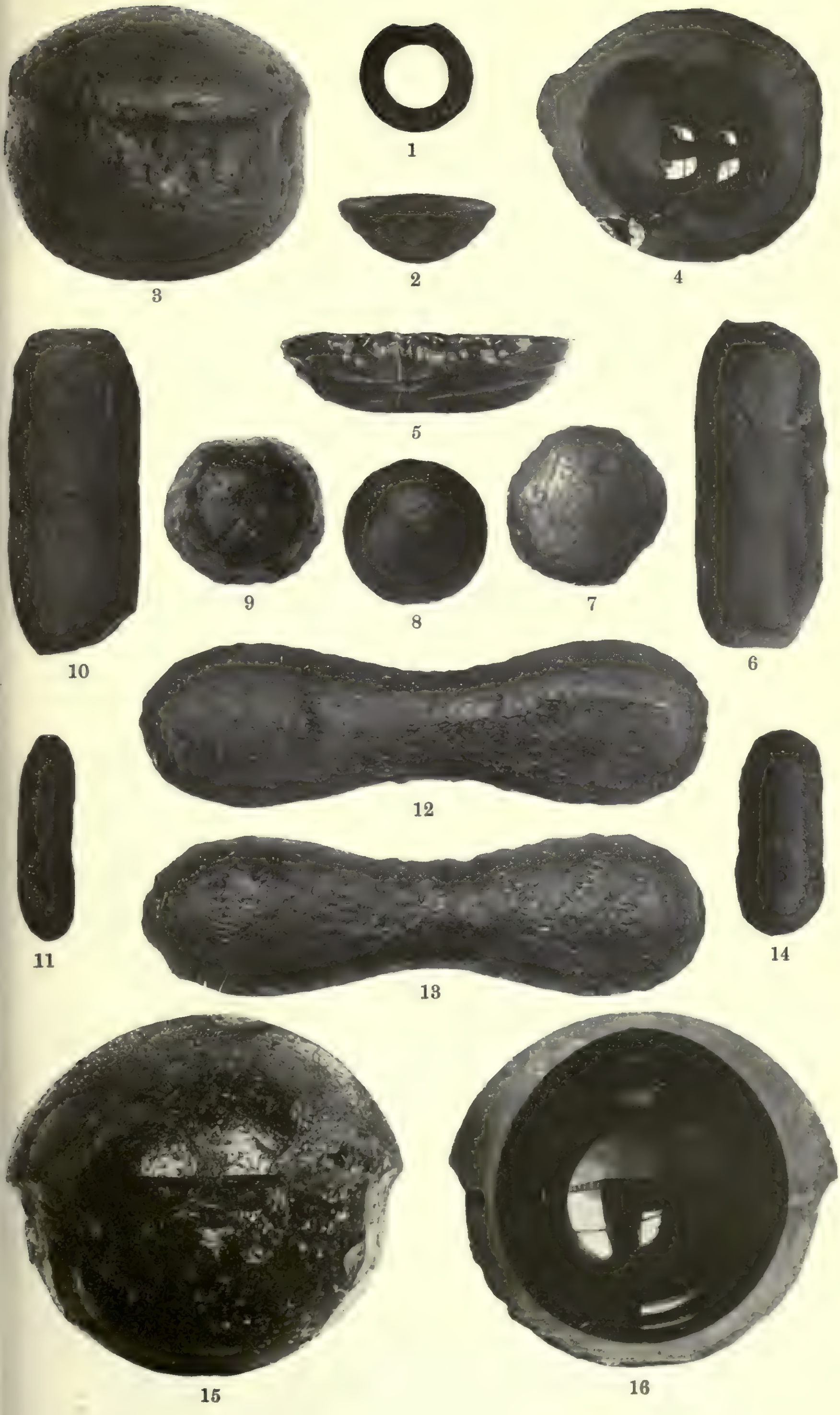
PLATE 57

PLATE 58



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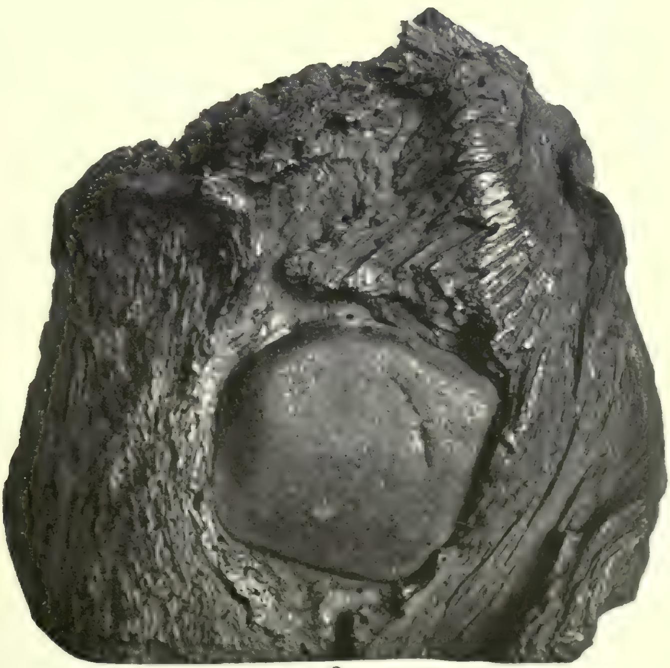

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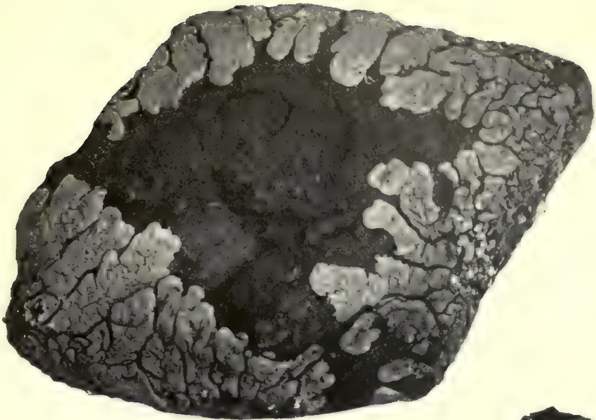

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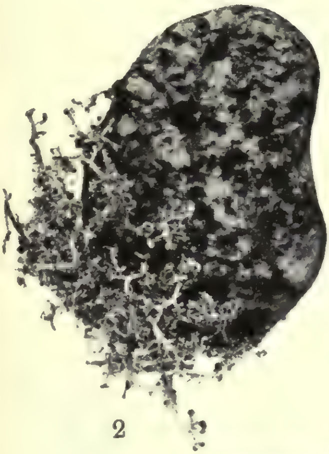

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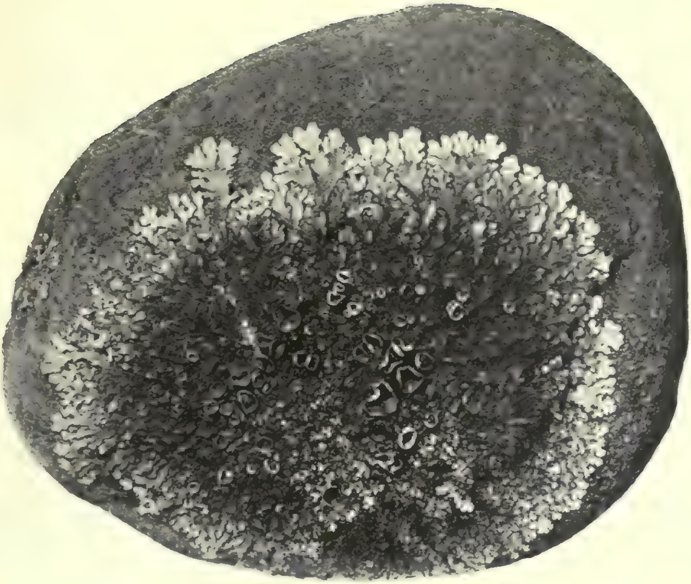

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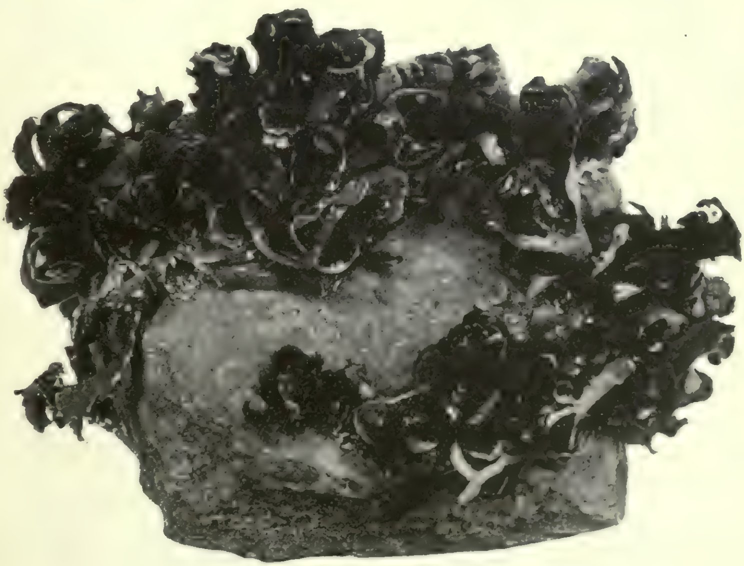

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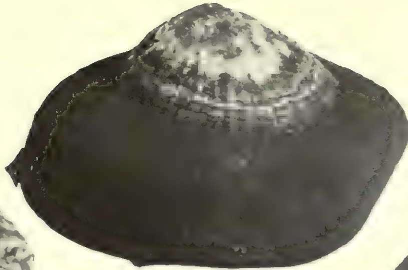

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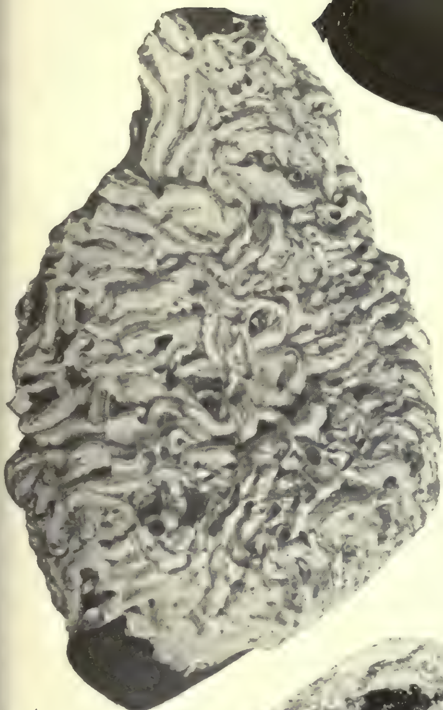

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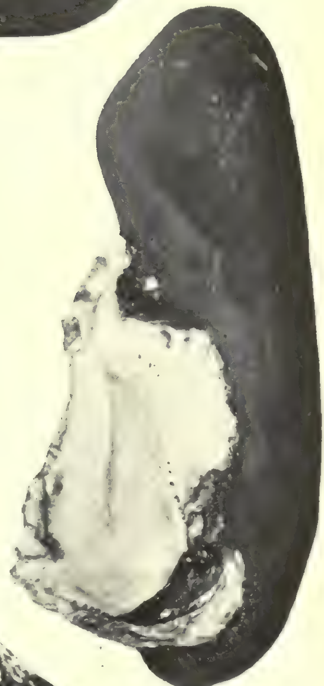

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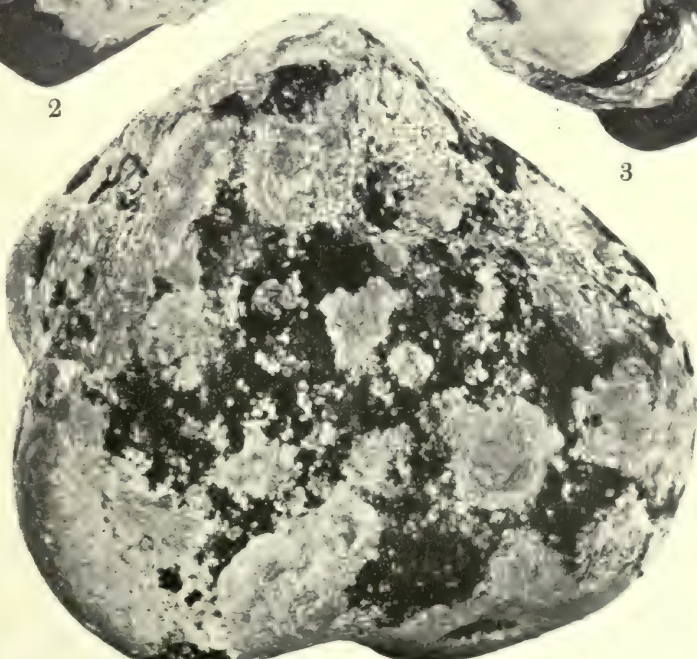

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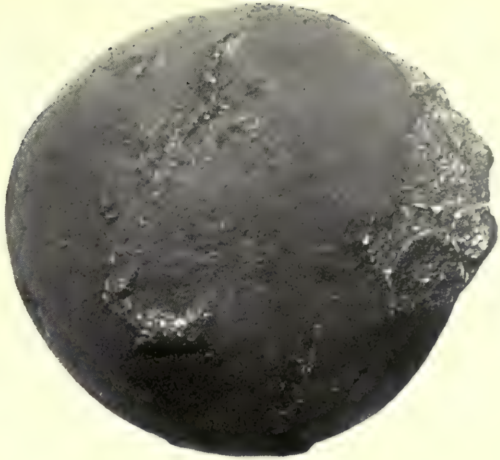

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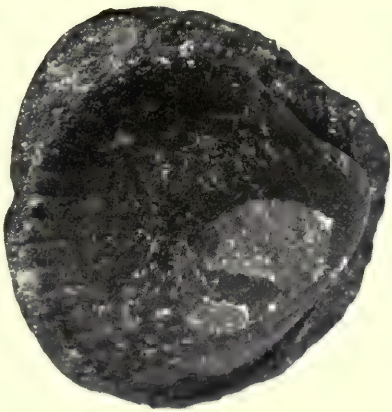

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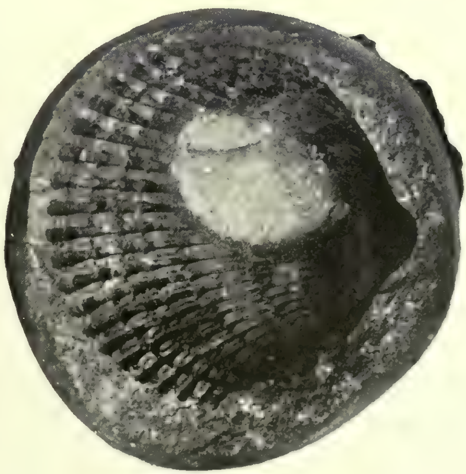

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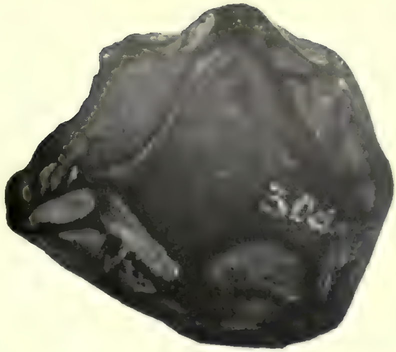

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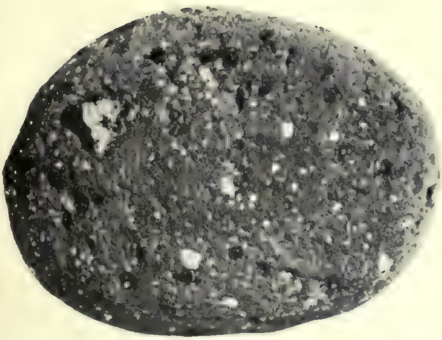

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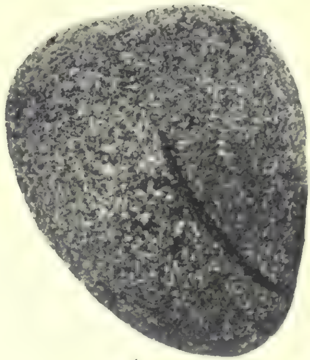

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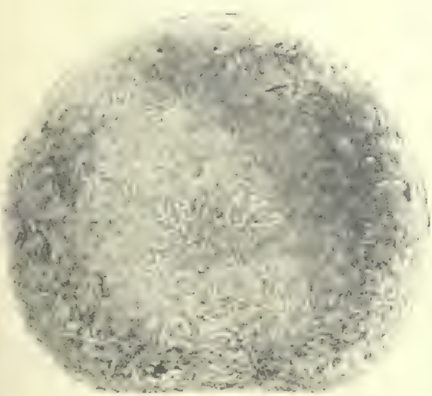

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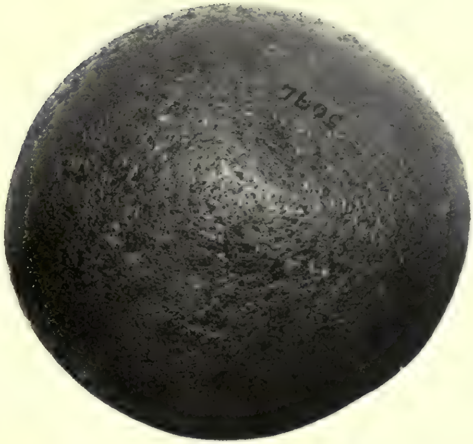

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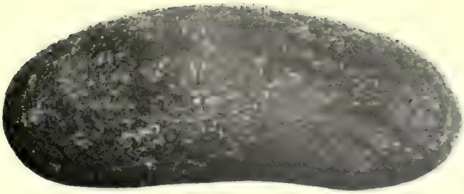
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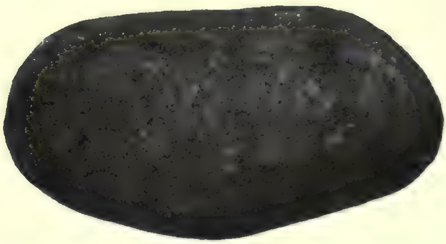
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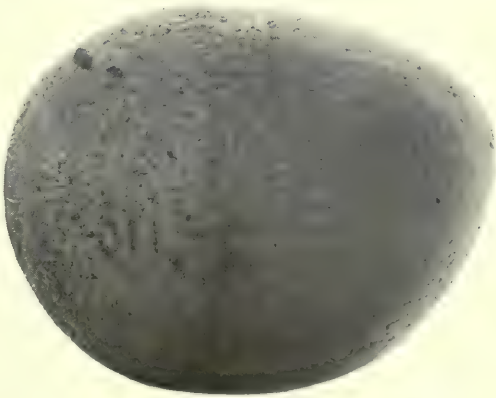
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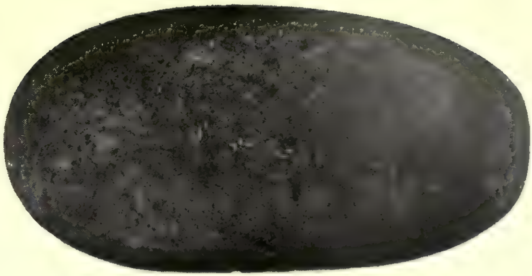

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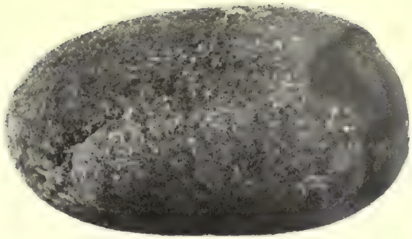

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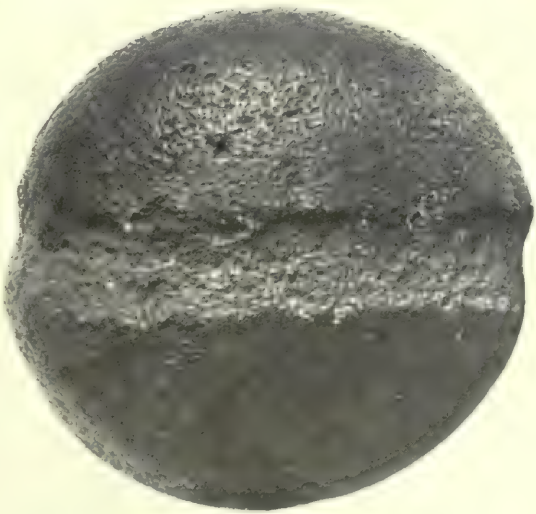

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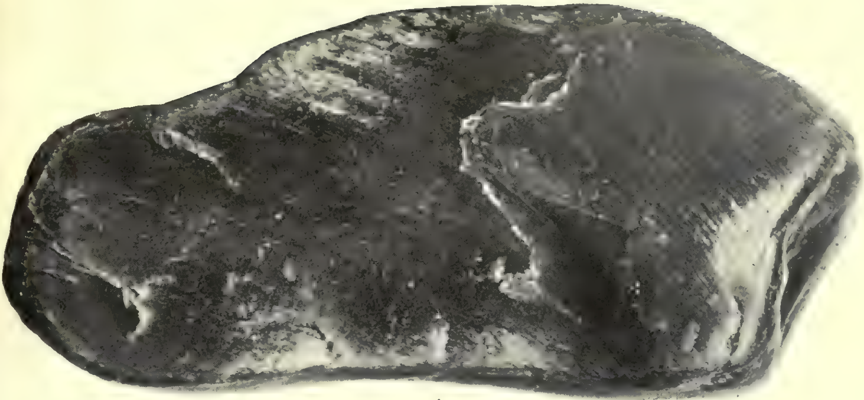

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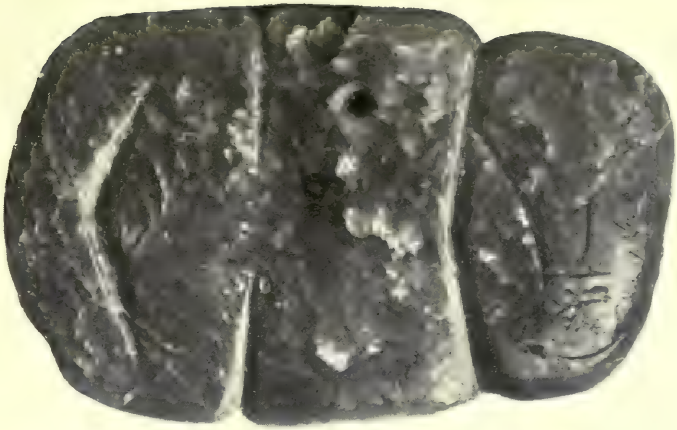
PLATE 76



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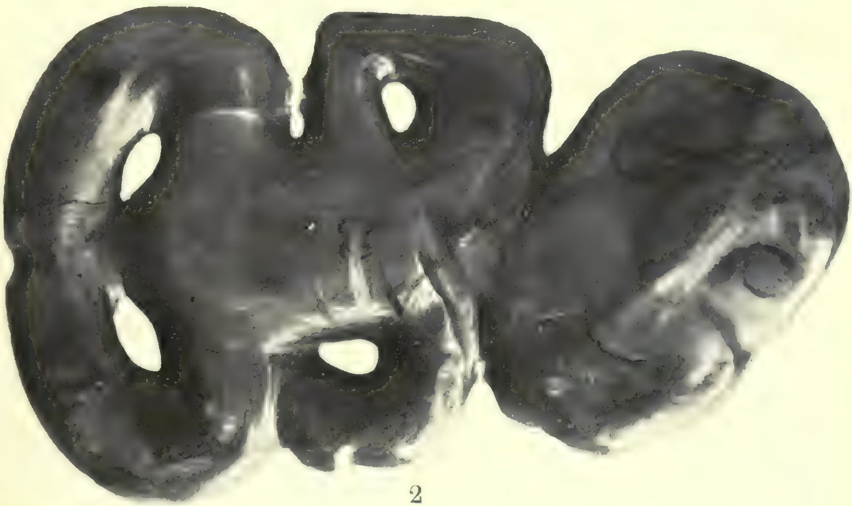

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